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THE EVALUATION OF AIR-TO-AIR COMBAT SITUATIONS BY NAVY FIGHTER PILOTS WITH ARTIFICIAL INTELLIGENCE APPLICATIONS

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THESIS

The Evaluation of Air-to-Air
Combat Situations by Navy Fighter Pilots
with Artificial Intelligence Applications

by

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ABSTRACT

The evaluations made by 36 Navy fighter pilots of 64 air-to-air combat situations are statistically analyzed to detect any significant differences between pilots' evaluative techniques in relation to their rank, flight hours and combat missions. Predictor equations are computed and used in a self-analyzing, self-modifying artificial intelligence program modeled on an instructor-flight student interactive situation.

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I. INTRODUCTION

From the legendary Baron von Richtofen to the popular Snoopy flying his doghouse through the comic strips, the image of the fighter pilot is one of an enigma capable of performing complex and dangerous tasks in an environment where fractions of a second can spell the difference between success and filure, life and death. This fascinating picture of a highly trained, assured and swaggering superbeing beckons to be studied; to have the mystique lifted. Hence, the impetus of this research: the fighter pilot.

Other than the satisfaction of human curiosity, the study of the fighter pilot -in this case the Naval fighter pilot- can ultimately result in improved training and selection of future pilots by understanding the activities of successful pilots; improved combat techniques by adaptation of the successful pilots' techniques; improved surface-to-air and air-to-air communications through better understanding; and improved electronic and mechanical pilot aids to enhance pilot performance.

A. OBJECTIVES

The objectives of this research lay in two major areas. The first was to address the questions of how Navy fighter pilots evaluate an air-to-air combat threat, i.e., pilot versus pilot situations. How does the pilot reach his decision? Can this decision be somehow quantified for

computer applications? What differences exist among pilots in their evaluations of air-to-air threat?

The second major area lies in the field of artificial intelligence. Classically concerned with games such as chess and checkers with well defined rules for determining success and failure [1, 2], artificial intelligence has seen little application in real life "games." A notable exception is Clarkson's portfolio program which has reached partial agreement with a successful bank trust administrator [3]. Heuristics, such as the minimax technique whereby a player will always attempt to minimize his maximum loss [4], and binary choice selection [5], although fine for board games, find little application in games of life. As stated by Rigney [6]:

> "For decision tasks in which the outcome is of great consequence and the time for decision is short, as in many military, business, and medical decisions, the strategy the decision maker uses is of special interest."

From the strategies hopefully revealed in the attainment of the first objective, an artificial intelligence application is sought. As brought out by Shepard [7], an obvious disparity exists between "the effortlessness and surety of most perceptual decisions and the painful hesitation and doubt characteristic of these 'higher level' decisions" and strategies. To overcome this disparity in a "game" of ill defined rules and high stakes is the objective of the artificial intelligence application.

B. DEFINITIONS

At this time some definitions of terms used throughout this research should be brought forward. Artificial intelligence as used in this study encompasses the construction of "computer programs which exhibit behavior that we call 'intelligent behavior' when we observe it in human beings [8]."

The area of artificial intelligence most apt for this study is decision making in game playing. Hence the game is defined as air-to-air combat as experienced in the Vietnam area of operations.

C. ASSUMPTIONS

Certain assumptions used throughout the study are:

(1) Data such as military rank and threat evaluation decisions can be placed on a quantifiable continuum.

(2) Since no criteria of deciding success or failure in the game exist short of actual combat results, expertise in the game will decide successes or losses.

(3) Expertise is directly proportional to military rank, flight hours and total number of combat missions.

(4) The data base used is a representative sample of Navy fighter pilots.

II. EXPERIMENTAL PROCEDURE-DETERMINING DECISION STRATEGY

In an attempt to isolate and identify the important variables considered by a fighter pilot in his evaluation of an air-to-air combat situation, a mail-out survey was designed. In the survey the subjects were asked to assume the following hypothetical situation:

(1) The subject is an airborne Target Area Combat Air Patrol (TARCAP) over enemy territory in Southeast Asia.

(2) The subject's aircraft is configured and armed for air-to-air combat only; hence, a fighter.

(3) The subject's primary mission is to intercept and destroy enemy air raids threatening friendly airborne strike forces.

(4) The TARCAP and immediate strike group is the only friendly force in the area. Therefore, the subject is free to fire at any threat without positive visual identification.

Eleven different items of additional information were then presented to the subject. These were presented in pairs yielding a total of 55 combinations. The items of information were:

(1) Relative position of enemy aircraft from the friendly strike group.

(2) Type of enemy aircraft.

(3) Number of enemy aircraft.

(4) Number of friendly aircraft.

(5) Range from friendly aircraft to enemy aircraft.

(6) Speed of enemy aircraft.

(7) Friendly aircraft capabilities.

(8) Altitude of enemy forces.

(9) Anti-aircraft activity in the area.

(10) Bearing of enemy from friendly forces.

(11 Closure rate of friendly and enemy forces.

The subject then had to choose which one of the pieces of information presented in each pair would be of greater value in evaluating the threat of, and in planning engagement tactics against, enemy air units. An additional alternative was given whereby each member of the pair could be evaluated as being equal in importance. Appendix A contains a sample of this questionnaire. Ninety-seven Naval aviators responded to this questionnaire of which 68 or 70.1% were pilots and 29 or 29.9% were Radar Intercept Officers, the second crewman in the F-4 Phantom jet. Eleven or 11.3% were F-8 Crusader pilots, the rest of the pilots being F-4 pilots. Sixty-three or 65.0% of the aviators had combat experience over Korea or Vietnam. Nine or 9.4% had engaged in actual air-to-air combat.

From a scaling of the variables from the pair-comparisons data the variables were ranked as follows (in descending order of importance):

(1) Relative position of enemy aircraft.

(2) Bearing of enemy.

(3) Range of enemy.

(4) Altitude of enemy.

(5) Friendly aircraft capabilities.

(6) Number of enemy.

(7) Rate of closure.

(8) Anti-aircraft activity.

(9) Type of enemy aircraft.

(10) Speed of enemy.

(11) Number of friendly.

From the results of the first survey, and with the consideration of the type of information available to the pilot in the cockpit, a second mail-out survey was designed. The variables considered in this survey were limited to six in number. Fuel states and rules of engagement were added for realism. The remaining four variables were considered as being information a pilot would have at his access from either his cockpit instruments or via a surface or airborne controller. The variables were limited to two states, hence 25 or 64 possible combinations were considered by each subject. The variables and their states were:

(1) Fuel above bingo; the maximum amount of fuel that can be utilized before fuel level drops below that necessary for a safe return to home base.

 (a) 1000 pounds.

 (b) 2500 pounds.

(2) Rules of engagement; when the subject may take the suspected aircraft under fire.

 (a) Eyeball (positive visual identification is required).

 (b) Missiles free (positive visual identification is not required).

(3) Enemy's relative bearing from the subject.

(a) 315°

(b) 135°

(4) Enemy's range from the subject.

(a) Eyeball or within 4 nautical miles.

(b) 20 nautical miles.

(5) Enemy's true heading or direction of flight.

(a) 045°

(b) 225°

(6) Number of enemy aircraft.

(a) 2

(b) 6

The subjects were asked for their rank, total number of flight hours and total number of combat missions. The following background scenario was used for each of the 64 situations:

"You are the flight leader of a section[1] of F-4's armed with two Sparrows[2] and two Sidewinders.[3] Assume for this exercise that the aircraft's weapon systems are up in every respect. You are providing

---

[1] A section normally consists of two F-4's.

[2] Beam riding guided missile.

[3] Heat seeking guided missile.

TARCAP for a division of A-7's who have just completed a strike and are egressing from the target area. You are feet-dry[4] over North Vietnam (20 nm to the coast). The AA and SAM[5] defenses in the immediate area are light to moderate. You have limited GCI[6] facilities operating for you and the enemy has excellent ground radar control.

The enemy aircraft are assessed to be MIG-21's at 15,000 feet and 500 kts. You are 10,000 feet and 450 kts. heading for your carrier (360° relative).

The weather in the area is clear and 15+ visibility. There are several flights of attack aircraft still feet-dry, exact position unknown.

The MIG's have demonstrated an air-to-air missile capability."

Figure 1 shows the way the tactical situations were presented to the subjects, analogous to a radar scope or maneuvering board's display.

Two major evaluation questions were asked of each subject in conjunction with each of the 64 situations considered. These questions are shown in Figure 2.

The questionnaire was sent to a number of Navy fighter squadrons on both the East and West Coasts. The aircraft in service at each of the squadrons was the F-4 Phantom. Thirty-six pilots responded. These pilots are described in Appendix B. Table 1 contains a description of the pilots by rank, hours and combat missions. The overall average

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[4]Over land vice feet wet or over water.

[5]Surface-to-Air Missile.

[6]Ground Control Intercept.

Figure 1

TACTICAL SITUATION PRESENTATION

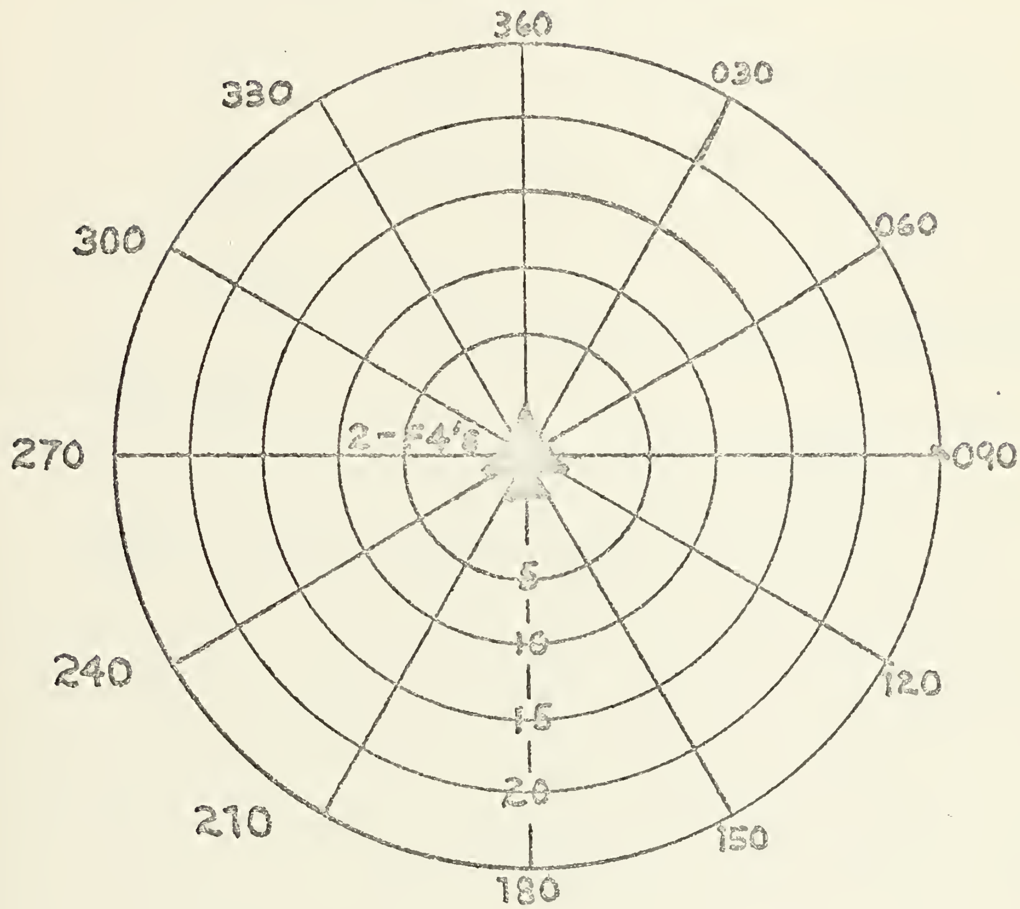

Figure 2

QUESTIONS ASKED WITH EACH TACTICAL DISPLAY

A. In this tactical situation (check <u>one</u> answer):

1. I'd have no choice; there would be an engagement.

2. I'd have a choice on whether to engage or not, and I'd engage.

3. I wouldn't engage.

B. Indicate what aircraft losses you would predict, if there were an engagement.

Enemy Losses__________________(no. of aircraft)

Friendly Losses________________(no. of aircraft)

respondee had a rank between Lieutenant and Lieutenant Commander (3.47)[7], 1994.03 flight hours and 124.11 combat missions. Rank was assumed to be an attribute providing ordinal data.

The data from the surveys were coded and placed on a magnetic disk for statistical analysis. The rules of engagement, being qualitative variables, were arbitrarily coded as a 0 for eyeball and 1 for missiles-free. A measure of central tendency (arithmetic mean) and measure of dispersion (standard deviation) was computed for each biographical variable (rank, flight hours, combat missions), each primary tactical decision and each secondary enemy and friendly kill decision made for the entire sample. Means and standard deviations of these variables and decisions were then computed for each subset of the sample defined by biographical data groupings, i.e., all Commanders, all Lieutenant Commanders, all Lieutenants, all Lieutenants (junior grade), all pilots with more than 4000 hours, all with less than 4000 and more than 3000, all with less than 3000 and more than 2000, all with less than 2000 and more than 1000, all with less than 1000, all pilots with over 300 missions, all with less than 300 and more than 200, all with less than 200 and more than 100, all with less than 100 and more than one mission and those pilots with no combat missions. Likewise, the mean and standard deviation of each decision was computed for the subset of the sample defined by holding each of the situational variables constant at one of

TABLE I

DESCRIPTION OF RESPONDING FIGHTER PILOTS

Rank:	LT(jg)	LT	LCDR	CDR
Number:	1	21	10	4
Hours: Mean	450.0	1394.29	2675.50	3825.00
S.D	0	438.54	553.69	466.61
Missions: Mean	0	96.52	163.40	201.75
S.D.	0	74.66	72.17	106.81

Hours:	0-999	1000-1999	2000-2999	3000-3999	4000+
Number:	5	17	6	6	2
Rank[7]: Mean	2.80	3.14	3.67	4.33	5.0
S.D.	.01	.88	.47	.47	0
Missions: Mean	0	127.07	111.83	242.00	106.50
S.D.	0	87.12	54.78	69.20	36.64

Missions:	0	1-99	100-199	200-299	300+
Number:	6	7	13	8	6
Rank[7]: Mean	2.83	3.38	3.54	3.71	4.50
S.D.	.37	.70	.63	.70	.50
Hours: Mean	763.33	2150.00	2065.77	2378.57	3250.00
S.D.	177.87	971.43	870.87	832.28	50.20

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[7]Ensign = 1, LT(jg) = 2, LT = 3, LCDR = 4, CDR = 5

its values and then the other while the remaining situational variables were free to assume either of their two values.

In attempting to find a relationship between the biographical and situational variables and the decisions reached, correlation coefficients were computed between these variables and decisions. These correlation coefficients were computed for the entire sample, for each subset defined by the biographical groupings, and for each respondee. These findings were presented to a panel of Naval aviators who were asked for their opinions and suggestions. These aviators are described in Appendix C. From their suggestions new variables made up of combinations of the original six variables were added to the data base and the same analysis again undertaken. This cycle was repeated until the panel considered the results to be reasonable.

In an attempt to distinguish any discernible differences between the decisions reached for each biographical subset within the rank, hour and mission groupings, a discriminant analysis was performed. In this analysis, a linear function for each subset within a group is computed using the subset characteristic (specific rank, hours grouping, or mission grouping) as the dependent variable and the decisions reached as the independent variables. These functions are then evaluated for each case and the hypothesis that the subset means are the same is tested [9].

In an attempt to predict a pilot or group of pilots' decisions, a sequence of multiple linear equations computed using stepwise multiple regression techniques were also produced for the entire sample and each subset. At each step in this regression procedure, one situation variable is added. The variable added is the one which makes the greatest reduction in the error sum of squares (the variable with the highest partial correlation with the dependent variable at that step). The production stops when the error sum of squares decreases less than .001 or until all variables are exhausted [10]. The correlation coefficient between these equation predictions and the actual decision reached was then computed for each situation examined. These equations and correlations were then presented to the panel of aviators for their evaluation.

III. RESULTS OF DATA ANALYSIS

A. VARIABLES ADDED AND DELETED

Since bearing and heading, although quantitative items of information shown to be important in the first survey, did not represent continuums that could be conveniently statistically manipulated, both were deleted in favor of a new variable. The reason this was done is apparent when evaluating, for example, bearings of 001° and 359°. Although separated by only 2° on a compass rose, a quantity evaluated by the panel of aviators as negligible, the values are separated by 357°, which is not negligible. Also, the two variables' effects on a pilot's evaluation appeared to be interactive. An enemy directly behind a friendly (bearing 180°) was evaluated differently if the enemy was pointed at the friendly (heading 360°) or pointing away (heading 180°). This pointing information is not directly available to the pilot from either his cockpit displays or GCI input. Yet the pilot does mentally integrate the bearing and heading information into pointing information. Consequently, a function of both bearing and heading was created. This function, called "danger angle," is described by the following equation:

$$\text{Danger (bearing, heading)} = (\sin(\text{bearing}) / |\sin(\text{bearing})|) \times [\text{bearing} - (\text{heading} + 180) \text{ modulus } 360].$$

Similarly, although pilots considered range and fuel-remaining as important variables independently, the aviator panel believed that a

link existed between these two factors. For instance, a fighter pilot's behavior in a situation of long range with low fuel remaining would probably be different from that under a situation of short range and a large amount of fuel remaining. Again, this would be a case of pilot integration of a cockpit display (fuel remaining) and a GCI input or radar display (range) into a range per fuel state factor. Consequently a range-fuel ratio (MPG) was created as described by the following equation:

$$\text{MPG (range, fuel remaining)} = \text{range/fuel remaining.}$$

As shown in the first mail-out questionnaire results, a relationship between the enemy's speed and heading and friendly speed and heading, or closure rate is considered by fighter pilots (See EXPERIMENTAL PROCEDURE DETERMINING DECISION STRATEGY). Again, pilot integration of cockpit and GCI inputs appears to occur: the pilot projecting the parallel enemy speed vector into his own. As a result, a speed differential function was created for the tactical scenario:

$$\text{Speed (heading, bearing)} = 500 \times \cos(\text{heading}) - (\cos(\text{bearing}) / |\cos(\text{bearing})|) \times 450.$$

In both the speed and danger equations, a value of +1 was assigned to the ratio of the trigonometric function and its absolute value when that function was equal to zero.

B. CORRELATIONS

The primary tactical decision made by the subjects was assumed to be ordinally quantifiable as indicated below:

(1) Pilot has no choice, an engagement would occur.

(2) Pilot has a choice and would elect to engage the enemy.

(3) Pilot would not engage the enemy.

The secondary decision was in two parts, number of enemy losses predicted and number of friendly losses predicted if an engagement were to occur.

The biographical data's correlation with the decision is shown in Table II for all pilots.

TABLE II

CORRELATION OF BIOGRAPHICAL DATA WITH PRIMARY AND SECONDARY DECISIONS

	Tactical Decision	Enemy Kills	Friendly Kills
Rank	-.0392	.0541	.2195
Hour	-.0394	.0628	.1685
Missions	-.0333	.0801	.1265

The lack of correlations significantly different from zero is striking. Only with the relationship of rank to friendly kills predicted can a coefficient of correlation be found of any sizeable magnitude (+.2195). Discriminant function analysis revealed no significant differences between the pilots when they were categorized by rank, hour or mission

with respect to the decisions they made (at a significance level of $\leq .05$) (See Appendix D). The panel of aviators considered this (post hoc) to be a result of standardized training and operational squadron procedures. They also expected a positive correlation between rank and expected friendly kills as a result of more realistic evaluation techniques acquired with time spent in operational billets. A decline in youthful optimism as one ascends the rank and age structure was also expected to enhance this postulated positive correlation. Appendix F contains the means and standard deviation of the decisions reached by the biographical groupings.

The situational variables' correlations with the decisions are shown in Table III.

TABLE III

CORRELATIONS OF SITUATIONAL VARIABLES WITH PRIMARY TACTICAL DECISIONS AND SECONDARY EXPECTED ENEMY AND FRIENDLY KILL DECISIONS

	Tactical Decision	Enemy Kills	Friendly Kills
MPG	.4259	-.2087	-.1237
Speed	.2559	-.2339	.0553
Danger	.2864	-.2857	-.0201
Fuel Remaining	-.1708	.3400	-.0203
Range	.4209	-.0163	-.1746
Number of Enemy	.1223	.0231	.2447
Rules of Engagement	-.0760	.2287	-.0512

The panel of aviators, however, felt a chronological relationship existed between the decisions, that is, the pilot evaluated the situation as a whole and then reached his primary tactical decision. After that decision had been reached, and with that result kept in mind, it was thought that the pilot then made his secondary decisions. Suggestions by the author that the decisions of kill possibilities would precede and influence the tactical decision were strongly rejected by the panel as unrealistic from their own experiences. Table IV shows the correlation between the primary and secondary decisions.

TABLE IV

CORRELATION BETWEEN PRIMARY AND SECONDARY DECISIONS

	Enemy Kills	Friendly Kills
Tactical Decision	-.4247	-.2307

The reader should note that the biographical variable of rank is the third most important variable when predicting secondary friendly kills.

C. VARIABLE MANIPULATION

The effects of holding specific situation variables constant on the decisions made is shown in Table V. MPG was not held constant since that would imply a simultaneous manipulation of range and the fuel-remaining variable.

The most striking phenomena evident in Table V is the ratio between predicted enemy kills and predicted friendly kills of over four to one. As explained by the senior member of the panel of aviators after observing this phenomena:

> "A pilot would be a fool to go into combat is he didn't think the odds were stacked heavily in his favor."

The inverse relationship evident in this table between range and friendly kills was considered by the aviators to be a function of aircraft type. The F-4 was considered by them to be more of a weapons platform than a classical dog-fighter while the MIG-21, a smaller and more maneuverable airplane, is better suited for close-in fighting. The shorter range and, consequently, time available to the F-4 weapons systems decreases some of this system's advantages over a MIG-21 resulting in a greater enemy opportunity to attack the friendly forces. Interesting conjectures can be made about the results that might be observed if the friendly plane were an F-8, a true dog-fighter...The slight increase in enemy kills with decreasing range which is evident in Table V was felt by the panel of aviators to be the result of an increased friendly missile kill probability.

The pushing of the tactical decision to the "must engage" pole with shorter ranges was felt to be an indication that a pilot naturally considers danger more imminent as the enemy closes; the shorter ranges decreasing the protector's options.

TABLE V

VARIABLE MANIPULATION-AVERAGE VALUE PER SITUATION

Variable	Value	Tactical Decision	Enemy Kills	Friendly Kills
Range	4	1.66	1.09	.37
	20	2.32	1.05	.15
Rules of Engagement	Missile Free	1.93	1.31	.23
	Eyeball	2.05	.84	.29
Number of Enemy	2	1.89	1.05	.11
	6	2.09	1.10	.41
Speed	0	1.71	1.42	.24
	0	2.28	.73	.28
Danger	0	2.03	.94	.23
	0	1.83	1.19	.29
Fuel Remaining	1000	2.12	.73	.27
	2500	1.86	1.42	.25
All Free	Mean	1.99	1.07	.26
	S.D.	.79	1.01	.62

The differences displayed in the decisions as rules of engagement are varied were also felt by the panel to reflect aircraft type. The F-4 is at its best when able to deliver the long range, unsuspected missile under missiles free conditions. A 40% drop in predicted enemy kills can be seen in Table V as the rule of engagement assumes the eyeball condition. Waiting for ranges to shorten for eyeball identification means losing the advantage of the long range punch. The decreased range forced on the pilot shows in Table V, as before; in an increase in predicted friendly kills but not, surprisingly, in a tactical evaluation pushed towards the "must engage" pole.

The greatly increased number of predicted friendly kills when the number of enemy is high, as shown in Table V, is considered to be a direct reflection of superiority in aircraft numbers. No matter how effective a protector may be, once the protectors are saturated, some of the enemy will reach the vulnerable friendly forces. Also, the more enemy present the more enemy the friendlies may destroy. The tactical decision's migration towards the "not engage" pole was felt by the panel to be a sign of caution by the friendly in light of a large enemy force; the gains of engagement being more than offset by the possible friendly losses.

The speed differences between the friendly and enemy forces appear to push the primary tactical decision towards the two poles of engage or not engage. A large speed differential coupled with opening

ranges implies, according to the panel, a friendly decision of leaving the friendly forces exposed for a long chase or staying with the friendlies and not engaging the enemy. The high closure rate, however, would force the friendly to engage but, as shown in the extremely high predicted enemy kills in Table V, would place the enemy in the F-4's most optimal firing envelope.

The enemy pointing at the friendly forces places the friendlies in the enemy's best firing envelope and, as shown in Table V, seem to force the friendly tactical decision to the defensive "must engage" pole. As a result, a rise in both predicted enemy and friendly kills can be seen. The enemy pointing away from the friendlies with its implied opening ranges drives the tactical decision to the "not engage" side with concurrent drops in both predicted kills.

The low enemy kills and "not engage" decision evident with low fuel state was interpreted by the panel as a sign for caution for the friendly pilot. Friendly kills rise in this low fuel state not only from enemy attacks but from destruction due to fuel exhaustion in combat. Higher fuel states give the pilot a greater margin in combat for increased maneuvering and chasing, resulting in the increased predicted enemy kills and greater friendly protection.

D. MULTIPLE REGRESSION

From the multiple regression analysis a ranking of situational variable importance was made for all pilots and for each rank, hour and mission group. Table VI gives these rankings for all pilots and for the rank groupings. Appendix G contains the hour and mission rankings. As can be seen, MPG or range, one a function of the other, play an important role in the tactical decision evaluation. Danger, except in the case of Commander where it switches position with speed, is next most important followed by speed.

In the importance of variables for secondary decision evaluation, the tactical decision is the most important in evaluating enemy kills while the number of enemy is the only variable more important in evaluating friendly kills. This may reflect the pilot's integration of his primary decision in his next evaluation, i.e., the pilot's "mental set" before actually making his next evaluations.

From this multiple regression analysis predictor equations were constructed. Described in Appendix E, the equations were used in predicting the decisions made on the decision survey. The obtained multiple correlations are described in Table VII and Appendix H.

TABLE VI

VARIABLE RANKINGS FOR ALL PILOTS AND RANK GROUPS IN DECISIONS REACHED

A. Tactical Decision

	ALL	CDR	LCDR	LT	LT (jg)
MPG	1	7		1	7
Danger	2	3	2	2	2
Speed	3	2	3	3	6
Range	4	1	1	5	1
Number of Enemy	5	4	4	4	4
Rules of Engagement	6	6	6	6	5
Fuel Remaining	7	5	5	7	3

B. Enemy Kills

	ALL	CDR	LCDR	LT	LT (jg)
Tactical Decision	1	1	1	1	1
Fuel Remaining	2	4	3	2	2
Rules of Engagement	3	6	4	3	8
Danger	4	5	2	4	4
Speed	5	8	5	5	3
Range	6	2	6	6	6
Number of Enemy	7	3	7	7	5
MPG	8	7	8	8	7

C. Friendly Kills

	ALL	CDR	LCDR	LT	LT (jg)
Number of Enemy	1	1	2	1	1
Tactical Decision	2	2	1	2	4
Speed	3	4	4	3	3
Rules of Engagement	4	3	7	4	5
Fuel Remaining	5	8	5	5	8
Danger	6	5	8	6	6
Range	7	7	3	7	2
MPG	8	6	6	8	7

TABLE VII

CORRELATION OF PREDICTED VALUES FOR DECISIONS AND ACTUAL DECISIONS MADE BY ALL PILOTS AND RANK GROUPINGS

	ALL	CDR	LCDR	LT	LT(jg)
Tactical Decision	.6032	.5794	.6236	.6101	.7568
Enemy Killed	.6027	.5859	.5654	.6527	.8193
Friendly Killed	.4015	.4391	.5299	.3732	.5284

It appears that the equations are fairly successful for the groups studied in predicting their tactical and enemy kill decisions.

In an attempt to secure a standard of comparison for these equations, the panel of aviators was used to predict one of the biographical group's decisions. The members of the panel, who were associated with the data at some length, considered themselves to be closest to the Lieutenant Commander group in rank, hours, and missions. All of the Lieutenants on the panel were in the current Lieutenant Commander selection zone. They attempted to predict the Lieutenant Commander group's decision rather than only making their own evaluations of the situations. The following correlations between the panel's predictions and the actual decisions made by the Lieutenant Commander group were found:

Tactical Decision	.5863
Enemy Killed	.5200
Friendly Killed	.4327

In essence, the predictor equations fared better than the predicting panel of aviators (See Table VII).

IV. EXPERIMENTAL PROCEDURE-ARTIFICIAL INTELLIGENCE APPLICATION

One writer [11] has described and defined artificial intelligence in the following way:

> "A human being can think, learn, and create because the program his biological endowment gives him, together with the changes in that program produced by interaction with his environment after birth, enables him to think, learn, and create. If a program thinks, learns, and creates, it will be by virtue of a program that endows it with these capacities. Clearly this will not be a program - any more than the human's is - that calls for highly stereotyped and repetitive behavior independent of the stimuli coming from the environment and the task to be completed. It will be a program that makes the system's behavior highly conditional on the task environment - on the task goals and on the clues extracted from the environment that indicate whether progress is being made towards those goals. It will be a program that analyzes, by some means, its own performance, diagnoses its failures, and makes changes that enhance its future effectiveness."

With the goal of the last sentence above in mind, the panel of aviators, all of whom have had student aviator instructor billets, described a student pilot's behavior in interaction with his instructor. Once past the basic ground schools, flight training appeared to entail corrective instruction of the student's cockpit actions. The corrective instruction can be broken down into three general areas:

(1) The student did the opposite of what he should have done.

(2) The student did too much of what he should have done.

(3) The student did not do enough of what he should have done.

For example; (1) pushing the stick to the left vice the right, (2) applying too much throttle, and (3) not using enough flaps. Such mistakes as

forgetting to lower the landing gear were considered as combinations or extremes of the three.

The student's response to the three corrections were:

(1) Reversing the sign or direction of what was incorrectly done.

(2) Lessening the magnitude of what was incorrectly done.

(3) Increasing the magnitude of what was incorrectly done.

Also, as the student pilot gains more experience his confidence level in himself and aircraft rises. His corrections grow smaller in magnitude resulting in a smoother development. As stated by one of the aviators on the panel:

> "Any movement which is not smooth and gentle in an aircraft is probably an incorrect movement."

In advanced Naval pilot training where such topics as tactics and gunnery are taught, the three instructive areas are thought to still exist. However, at this level the pilot is developing his evaluative skills rather than his motor skills. Since multi-level decisions are involved, the student is not allowed to proceed to the next level until the present level decision or action is correct. Figure 3 displays this macro-level education concept.

This concept, if captured in a program, would enable the program to analyze its performance and diagnose its failures (instructor correction) and make changes to enhance its future effectiveness (student modification). This program could show some attributes (confidence and

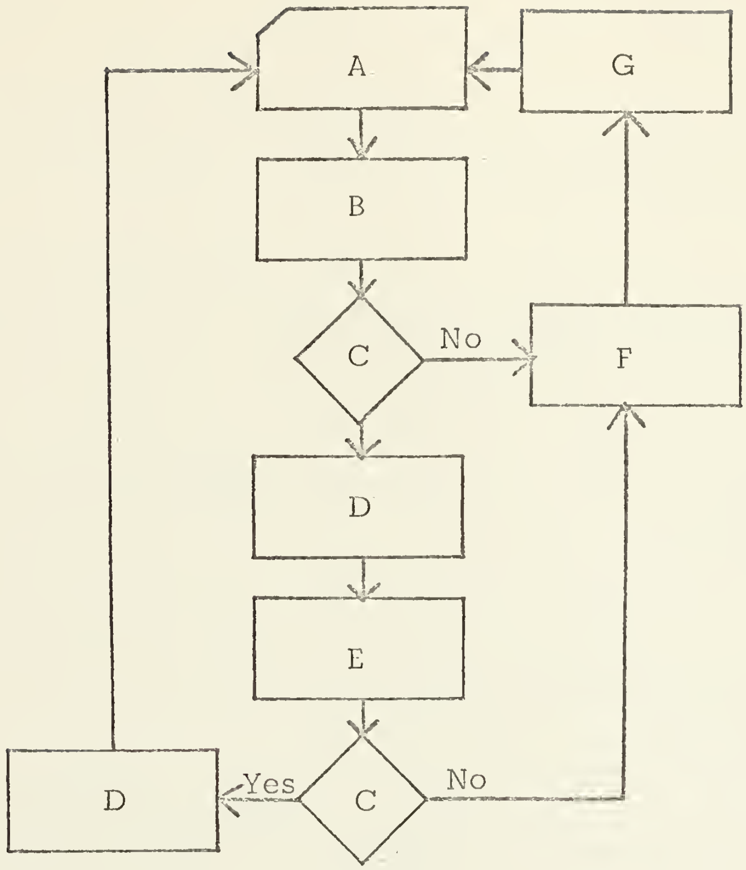


Figure 3

MACRO-LEVEL PILOT EDUCATION

A: Present situation to student.

B: Student evaluates situation and makes primary decision.

C: Is decision correct?

D: Student gains confidence and experience.

E: Student makes secondary decisions.

G: Student modifies own evaluation techniques.

experience, learning, fallibility) that, if witnessed in a living organism, would certainly be termed intelligent. Hence, an artificial intelligence approach to this macro-level pilot learning concept was initiated.

Certain restrictions were placed on this artificial intelligence programming attempt. Since possible graphics adaptations were envisaged, memory size limitations were desired. The available graphics terminal at Naval Postgraduate School is an AGT-10 with limited memory. Also, as brought out by the panel of aviators, a pilot does not consciously search through his memory looking for a situation or solution but rather appears to act at a level of perceptual decision making [7]. Likewise, the panel considered the classical tree searching and minimaxing procedures as unrealistic for this problem. Computer run time was to be as short as possible for both the practical consideration of program turn around time and because of the desire for instantaneous decisions as in high speed air-to-air combat. Consequently, a polynomial evaluation with adaptation of the coefficients technique was chosen along the lines of Samuel's checker player [2]. The coefficient would, in essence, act as a quasi-memory, reflecting change but not, necessarily, history. FORTRAN IV was chosen for the program language over ALGOL and LISP because of future graphics applications where no ALGOL or LISP compilers would be available.

The "instructor" would be one of the pilot groups for which a predictive equation existed. The instructor's memory would contain the predictive equation and all of the decisions made concerning the 64 situations presented in the second survey. The "student" would contain a predictive equation, either from actual data analysis, or a dummy one. It would have no decision history memory.

A. PROGRAM DESCRIPTION

The following matrices and vectors of interest are used throughout the program:

(1) sit (i,j) $i = 1, 64; j = 1, 6$
This matrix contains the six situational variables of the second array:

$j = 1$ - fuel remaining,
$j = 2$ - range,
$j = 3$ - bearing,
$j = 4$ - heading,
$j = 5$ - number of enemy,
$j = 6$ - rules of engagement.

They are presented in the 64 different situations, i going from 1 to 64.

(2) mem (i,j) $i = 1, 64; j = 1, 3$
This matrix contains the three decisions made by the instructor over the 64 situations:

$j = 1$ - primary tactical decision,
$j = 2$ - secondary enemy kills decision,
$j = 3$ -- secondary friendly kills decision.

(3) prico (1) i = 1, 8
This vector contains the instructor's primary tactical decision predictive equation coefficients for the variables below:

i = 1 - a constant
i = 2 - fuel remaining
i = 3 - range
i = 4 - number of enemy
i = 5 - rules of engagement
i = 6 - danger
i = 7 - speed
i = 8 - MPG

(4) startp (i) i = 1, 8
Completely analogous to prico, this vector contains the student's primary tactical decision coefficients.

(5) secoen (i) i = 1, 9
This vector contains the instructor's secondary enemy kills decision predictive equation coefficients for the same variables as in prico. When i = 9, the coefficient is for the primary tactical decision reached.

(6) secofr (i) i = 1, 9
This vector is the same as secoen but for the secondary friendly kills decision predictive equation.

(7) starse (i) i = 1, 9
Completely analogous to secoen, this vector contains the student's secondary enemy kills decision coefficients.

(8) starsf (i) i = 1, 9
Completely analogous to secofr, this vector contains the student's secondary friendly kills decision coefficients.

(9) kor (i) i = 1,8
This vector is the vehicle for the instructor's correction of the student's startp coefficients.

(10) kore (i) i = 1,9
This vector is the vehicle for the instructor's correction of the student's starse coefficients.

(11) korf (i) $i = 1, 9$
This vector is the vehicle for the instructor's correction of the student's starsf coefficients.

1. Main Program

The main program contains, in essence, the previously described macro-level pilot education concept. The 64 situations are read in (sit(i,j)) followed by the instructor's decisions over these situations (mem(i,j)) followed by the instructor's predictive equations (prico(i), secoen(i), secofr(i)). This constitutes the instructor's memory and expertise, his references and standards. Next, the student is brought into the scene by the reading of his starting evaluation equations (startp(i), starse(i), starsf(i)), these data representing the starting student at the beginning of the interactive instructor-student-situational process.

Next, for each of 900 trials, one of the 64 situations is picked at random and presented to the student. After calculating danger, speed and MPG; a skill hopefully developed through previous training, but probably never applied, the student makes the primary tactical decision for situation I:

$$\begin{aligned} \text{IDECIS} = {} & \text{startp}\ (1) + .5 + \text{startp}\ (2) \times \text{sit}(I,1) \\ & + \text{startp}\ (3) \times \text{sit}(I,2) + \text{startp}\ (4) \times \text{sit}(I,5) \\ & + \text{startp}\ (5) \times \text{sit}(I,6) + \text{startp}\ (6) \times \text{danger} \\ & + \text{startp}\ (7) \times \text{speed} + \text{startp}\ (8) \times \text{MPG}. \end{aligned}$$

A subroutine INSTRU is now called. This is equivalent to the instructor grading the student by saying "You've acted in the wrong

direction"; "too much"; "too little"; or "correct." From this grade the student is either sent on to make his secondary decisions (correct) or his primary evaluation equation is sent to KORECI subroutine for modification. If the student's grade is "not correct," upon returning from modification he returns to the beginning to have another situation presented without attempting to make a secondary decision. If no modification is needed, the student's experience and confidence level is increased and the secondary decisions are made for situation I:

IIEK = starse (1) + .5 + starse (2) x sit(I,1)
+ starse (3) x sit(I,2) + starse (4) x sit(I,5)
+ starse (5) x sit(I,6) + starse (6) x danger
+ starse (7) x speed + starse (8) x MPG
+ starse (9) x IDECIS (enemy kills),

IIFK = starsf (1) + .5 + starsf (2) x sit(I,1)
+ starsf (3) x sit(I,2) + starsf (4) x sit(I,5)
+ starsf (5) x sit(I,6) + starsf (6) x danger
+ starsf (7) x speed + starsf (8) x MPG
+ starsf (9) x IDECIS (friendly kills).

As in INSTRU, these decisions are graded by subroutine GRADER. These grades are considered after which either the student's equations are modified by KOREII or KORFII or his experience and confidence levels are increased. In either case, the student is sent back to the beginning for a new situation. The grading and correcting of the secondary enemy kill and friendly kill decisions are handled independently, hence correction may take place in one but experience and confidence may rise in the other.

2. Subroutine INSTRU

INSTRU first determines if it agrees with the student's primary tactical decision by checking the instructor's memory for the same situation (mem(I,1)). If the instructor and the student agree this fact is immediately returned to the main program. If there is no agreement, the instructor undertakes a coefficient by coefficient comparison of its own predictive equations (prico) with the student's evaluation equation (startp) for the primary decision. First compared as to sign and then as to magnitude, a grade is sent back to the main program for each coefficient; e.g., wrong sign, too small, too large, or, agrees with instructor's coefficient. The coefficient comparison is undertaken only when the student's primary decision does not agree with the instructor's.

3. Subroutine GRADER

Subroutine GRADER is essentially the same as subroutine INSTRU but deals with the grading and coefficient comparison of the two secondary decision equations. The two secondary decisions are handled independently.

4. Subroutine KORECI

Subroutine KORECI handles the modification of the student's equation for his primary tactical decision. A student's attempted correction of the same error is not necessarily stable in magnitude,

especially when he is first beginning to learn to fly. As a student's experience and confidence grows, however, the modifications become more consistent and decreasing in magnitude. Consequently, an experience modification factor, ZZ, is set. Previous runs had shown that multiplicative modifiers differing more than about .11 from 1 caused an erratic and sudden convergence of the student's coefficient to that of the instructor's. Therefore, it was decided to limit the modification factor to the closed interval [9, 1.1].

The experience modification factor is set by taking a uniformly distributed random number from the open interval (0,1). A different number is chosen each time KORECI is called. This number is then divided by the sum 10 + .1 x experience and confidence level. This experience and confidence level (X) is simply the number of correct primary tactical decisions that have been made. Hence the experience modification factor (ZZ) is in the open interval (0,.1). Adding or subtracting ZZ from one produces a modification factor in the open interval (.9,1.1) that approaches unity. For example; a starting random number of .5 with no experience and confidence gives a modification factor of .95 or 1.05, a starting random number of .5 with an experience and confidence level of 200 gives a modification factor of .98 or 1.02, and a starting random number of .9 with an experience and confidence level of 1000 gives a modification factor of .99 or 1.01.

After the experience modification factor is set, the student's coefficients are checked to see if the variable paired with that coefficient is even being considered, i.e., is the coefficient zero? If so, subroutine NOVICE is called, which means that more intensive instruction is given, or, a return is made to a more elementary student state. If not, the coefficients' gradings are examined and the coefficients are modified according to the results of these gradings. If a wrong sign is indicated, the student's coefficient is multiplied by -1. If the coefficient is too great in magnitude, the student's coefficient is multiplied by the modification factor 1-ZZ. If the coefficient is too small, the modification factor is 1+ZZ. A coefficient determined by INSTRU as being correct is not modified.

5. <u>Subroutine KOREII</u>

Subroutine KOREII is essentially the same as subroutine KORECI but handles the secondary enemy kill decisions. The experience and confidence level is the total number of correct secondary enemy kill decisions made by the student.

6. <u>Subroutine KORFII</u>

Subroutine KORFII is identical to subroutine KOREII but handles the secondary friendly kill decisions. The experience and confidence level is the total number of correct secondary friendly kill decisions made by the student.

7. Subroutine NOVICE

The object of this subroutine is to instruct the student to consider a variable that, up to this time, was not being considered (coefficient of zero). Since data had revealed that out of 330 coefficients considered in the analysis of all pilots and rank, hours, and mission groups, 329 fell into the interval (-30,30), a uniformly distributed random number is selected from the interval (-30,30) each time NOVICE is called. This is then given the sign of the instructor's coefficient for that variable and assigned to the student's coefficient in lieu of the previous zero value.

8. Subroutine RANDOM

This subroutine, a slightly modified version of IBM's RANDU [12], simply generates a uniformly distributed random number in the interval (0,1).

(All routines can be found in the Computer Printout Section of this thesis).

B. RUNNING THE PROGRAM

The program was run with the average pilot for the entire sample, the statistically average pilot from each rank group, the statistically average pilot from each hour group and the statistically average pilot from each mission group as instructors with the same groups' predictor equations as starting coefficients for the students. Therefore, each

instructor was run with all of these average pilots as students. As can be seen in Figures 4 through 15 and Table VIII, little differences exist between the instructor-student performances.

As a result of these runs, a synthetic beginning student was constructed with all starting coefficients set to zero. Using this beginner model as a student, the program was rerun with: 1) the average pilot for the entire sample, 2) the Commander group, 3) the 4000-plus hour group, and 4) the 300-plus mission group as instructors. The latter three groups were chosen for their expertise under the assumption that a pilot who has attained higher rank, flown 4000 non-fatal hours or survived 300 missions must possess some expertise in flight. The results obtained from this "beginner" student run were plotted and compared to those of the average student (See Figures 4-15, 16-27 and Table VIII). These comparisons and plots were then presented to the panel of aviators for their comments and criticisms.

TABLE VIII

RESULTS OF PROGRAM RUNS WITH TWO STUDENTS AND FOUR INSTRUCTORS

Average Pilot as Student:

Time* to Make First Correct Decision

Instructor:	Average Pilot	CDR	4000+	300+
Primary Decision	5	5	5	5
Secondary Enemy Kills	5	5	5	5
Friendly Kills	5	5	5	5

Time* to Attain 90% of Final Correct Percentage After First Correct Decision

Instructor:	Average Pilot	CDR	4000+	300+
Primary Decision	5	62	40	96
Secondary Enemy Kills	19	39	8	73
Friendly Kills	5	57	8	95

Final Correct Decision Proportions

Instructor:	Average Pilot	CDR	4000+	300+
Primary Decision	.85	.67	.87	.83
Secondary Enemy Kills	.72	.63	.60	.55
Friendly Kills	.94	.71	.62	.64

Synthetic Beginner as Student:

Time* to Make First Correct Decision

Instructor:	Average Pilot	CDR	4000+	300+
Primary Decision	200	221	199	206
Secondary Enemy Kills	129	194	172	149
Friendly Kills	157	177	161	177

Time* to Attain 90% of Final Correct Percentage After First Correct Decision

Instructor:	Average Pilot	CDR	4000+	300+
Primary Decision	40	47	48	83
Secondary Enemy Kills	137	40	32	104
Friendly Kills	56	111	72	225

Final Correct Decision Proportions

Instructor:	Average Pilot	CDR	4000+	300+
Primary Decision	.84	.65	.86	.83
Secondary Enemy Kills	.72	.61	.60	.55
Friendly Kills	.93	.71	.60	.61

*Time is in units of trials for the primary decision and in units of correct primary decisions for the secondary decisions.

V. RESULTS OF PROGRAM RUNS

A. AVERAGE PILOT AS STUDENT

For the case of the average pilot for the entire sample as the student, a successful evaluation of the situations occurred early in the runs, i.e., within the first five trials for all instructors. As can be seen in Table VIII, the average pilot instructing the average pilot had the highest overall average of correct decisions: 85% for the primary tactical decision, 72% for the secondary enemy kill decision and 94% for the secondary friendly kill decision. Naturally, the student's ending coefficients were the same as the student's starting coefficients since they are identical to the instructor's. The extremely high percentage of secondary friendly kill decisions is puzzling in light of the low correlation coefficient of .4015 between the predictor equation with actual secondary kill decisions made. Varying the random number seed changed that percentage negligibly. An explanation may lie in the fact that the rounding of the program decision equations to the nearest integer improved the accuracy of the prediction with respect to the correlation observed. For example, a predicted value of 1.49 friendly kills would be rounded to one friendly kill by the artificial intelligence program. Assuming the actual friendly kill decision to be one friendly kill, the artificial intelligence program would show a higher correlation than the straight predictor equations.

On the assumption that a student, upon reaching 90% of his final performance, is near matriculation, the time for his running percentage of correct decisions to reach 90% of his final percentage after his first correct decision was calculated. The running percentage of correct decisions reached 90% of the final percentage within five trials for the primary tactical decision, five correct primary decisions (a correct primary decision corresponds to a trial for the secondary decision) for the secondary friendly kill decision and 19 correct primary decisions for the secondary enemy kill decision.

The Commander instructor, as can be seen in Table VIII, whose predictor equations differed the most from the average pilot's, showed the lowest final percentage of successful decisions except in the case of the secondary friendly kill decision; 67% for the primary tactical decision, 63% for the secondary enemy kill decision and 71% for the secondary friendly kill decision. The high friendly kill decision percentage may be a reflection of a rank-friendly kill correlation witnessed in the data analysis (See Table II). The running percentage of correct decisions reached 90% of the final percentage within 62 trials for the primary decision, 39 correct primary decisions for the enemy kills and 57 correct primary decisions for the friendly kills. These longer learning times are felt to be reflections of the instructor and student coefficient differences.

The 4000-plus hour instructor, as can be seen in Table VIII, closely matched the average pilot instructor in final percentage of primary tactical decisions with 87% and neared the Commander instructor in final percentage of secondary enemy kill decisions with 60%. The 4000-plus instructor displayed the lowest secondary friendly kill decisions with 62%. The time for running percentages to reach 90% of the final percentages for this run were moderately low at 40 trials for the primary decision, and eight correct primary decisions for both secondary decisions. The low number of primary decisions correct needed to reach 90% of the secondary percentages is a reflection of the lower final percentages.

The 300-plus mission instructor, as shown in Table VIII yielded final percentages of 83%, 55% and 64% for the primary and secondary enemy and friendly kill decisions, respectively. Running percentages reached 90% of final percentages within 96 trials for primary decisions, 73 correct primary decisions for the secondary enemy kill decision and 95 for the friendly kill decision. These longer learning times are felt to be a result of the modification factor (ZZ) rather than a reflection of lower percentages or instructor student differences. Although no such run was made, the panel of aviators felt that a changed random number seed would show reduced learning times.

However, as can be seen on the graphs of total decisions right versus total trials or total primary decisions correct (See Figures 4-15),

the results are similar and nearly linear for all cases. The panel of aviators felt this pattern to be consistent with their own experience, i.e., as a result of standardization of procedures and training, different instructors teaching similar pilots would have, for the most part, similar results. They also considered the student, the average pilot from the sample, as more experienced than the actual student encountered in a flight syllabus. However, in a refresher or replacement training situation where the student is experienced, such rapid attainment of consistent results as witnessed in the graphs is felt by the panel to be typical.

B. SYNTHETIC BEGINNER AS STUDENT

The synthetic beginner student, with all starting coefficients set to zero displayed a radically different behavior than that of the average pilot (See Table VIII). At the end of 900 trials, all the running percentages for the last 100 decisions were equal to the final percentages witnessed when the average pilot was the student. Inspection of the runs revealed the interesting phenomenon of long error periods followed by rapid learning to a steady percentage.

With the average pilot as instructor, the first correct primary tactical decision was reached on the 200th trial. The first correct secondary enemy kill decision was not reached until after 129 correct primary decisions had been made, the first correct secondary friendly kill decision was not reached until after 157 correct primary decisions.

Figure 4

AVERAGE STUDENT-AVERAGE INSTRUCTOR

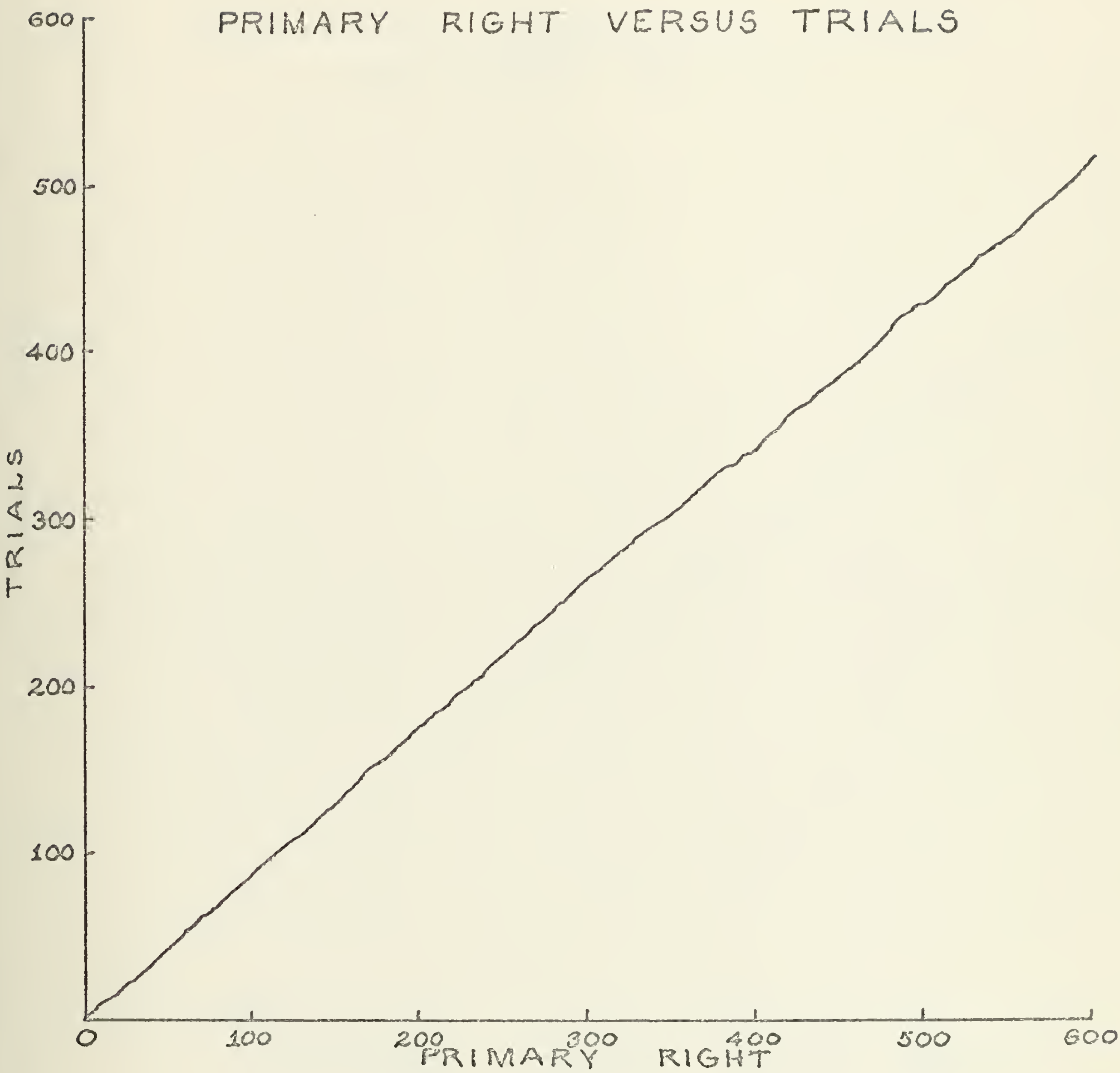


Figure 5

AVERAGE STUDENT-AVERAGE INSTRUCTOR

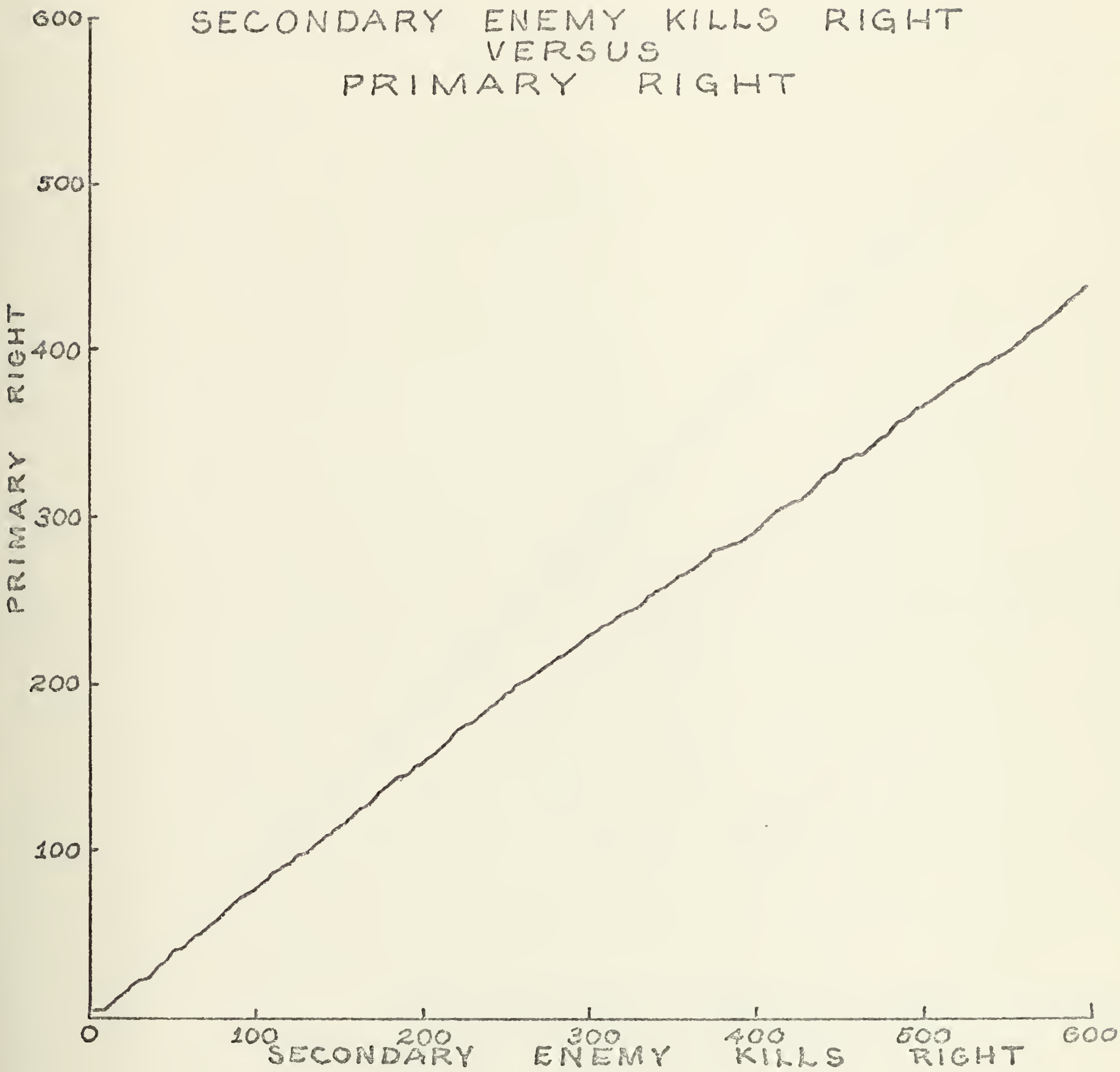


Figure 6

AVERAGE STUDENT-AVERAGE INSTRUCTOR

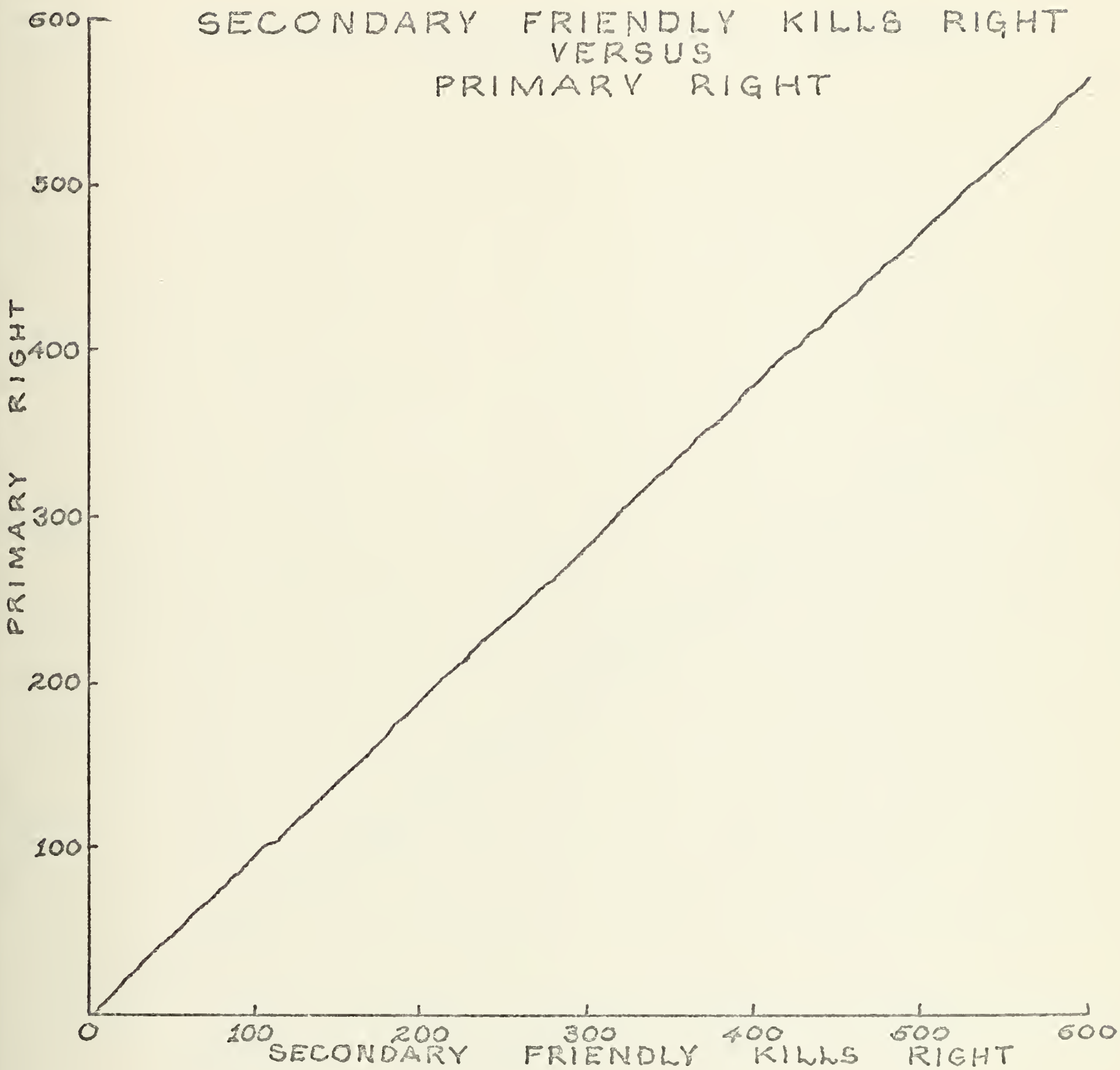


Figure 7

AVERAGE STUDENT-CDR INSTRUCTOR

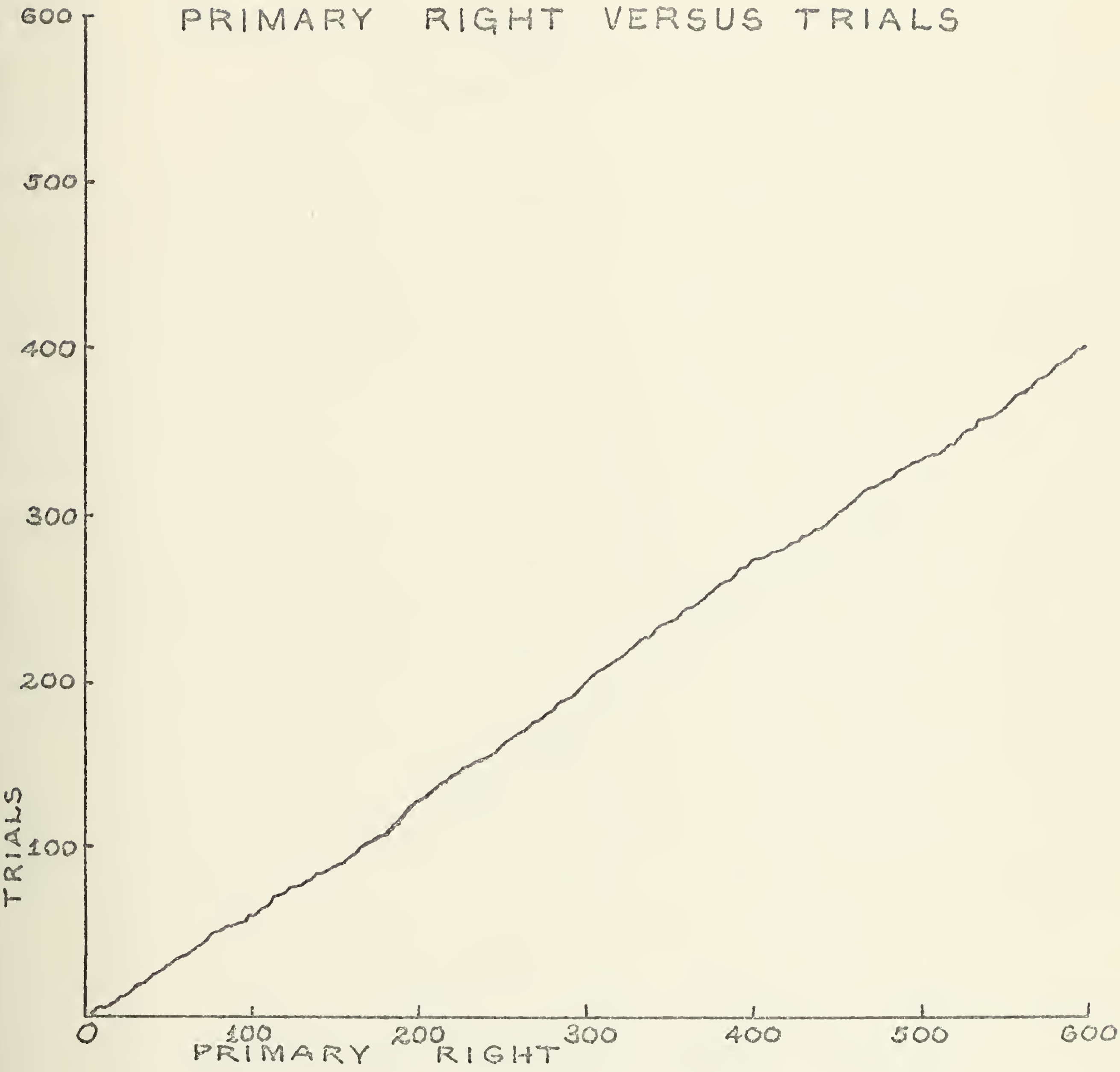


Figure 8

AVERAGE STUDENT-CDR INSTRUCTOR

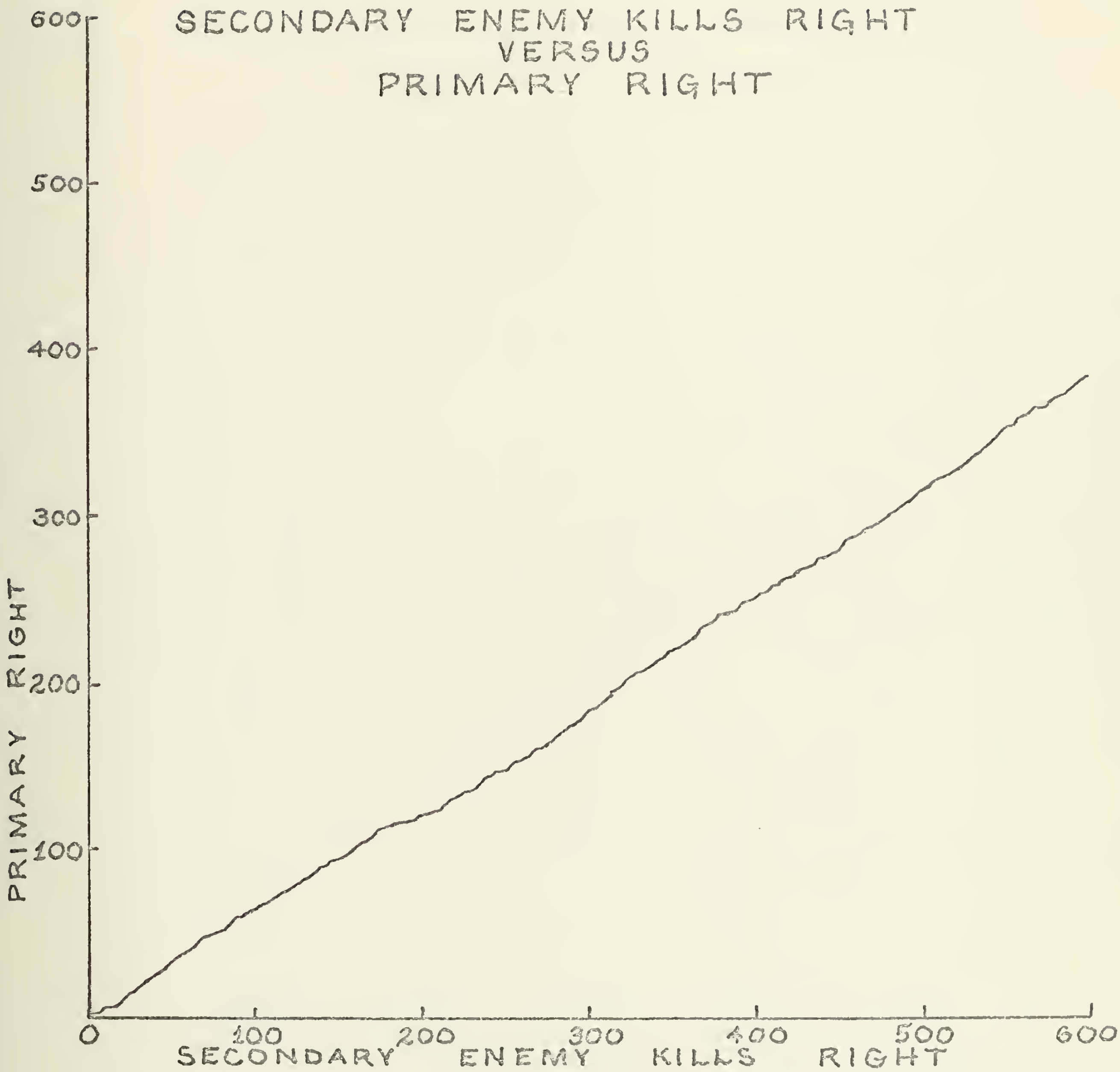


Figure 9

AVERAGE STUDENT-CDR INSTRUCTOR

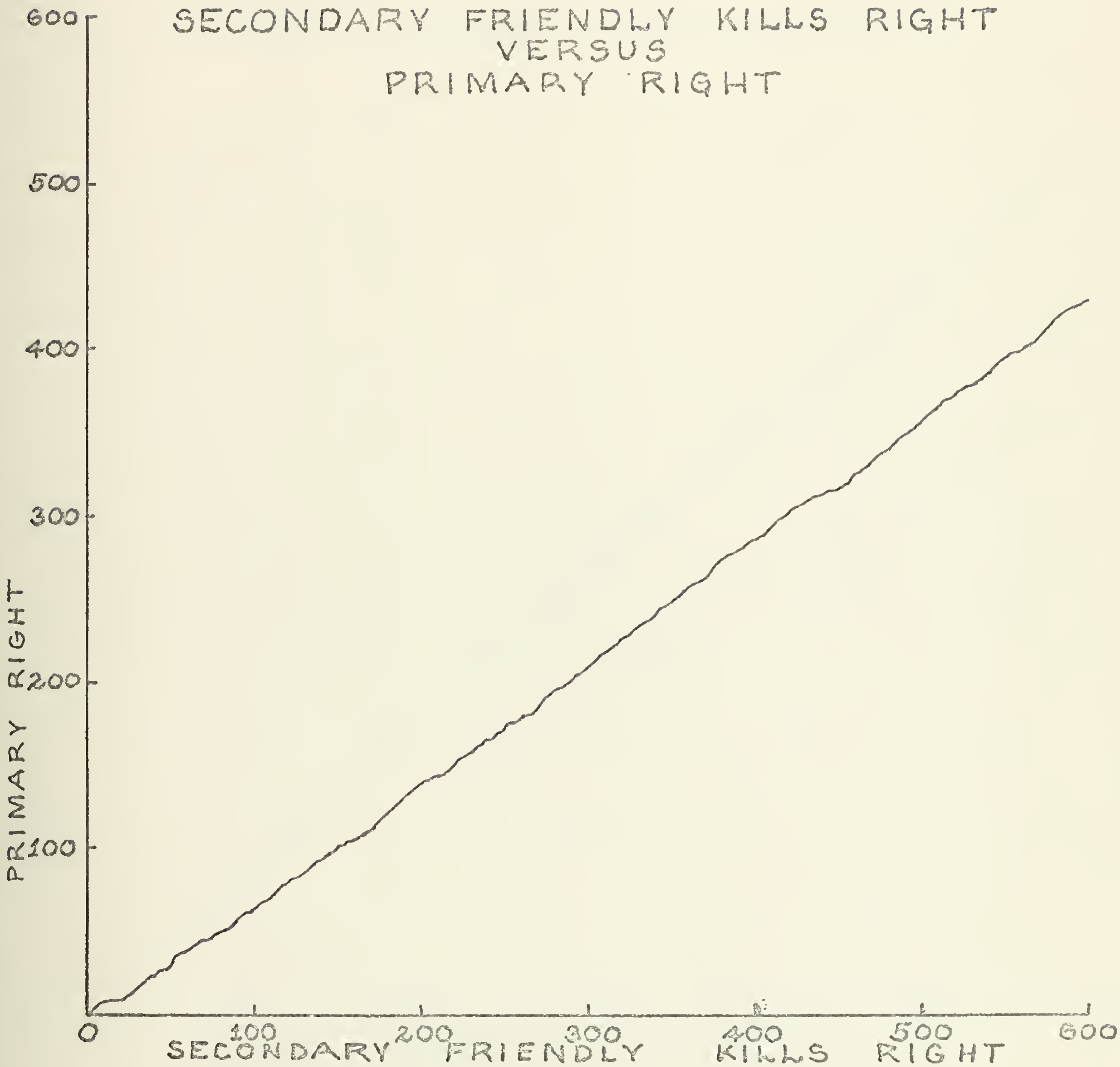


Figure 10

AVERAGE STUDENT-4000 HOUR INSTRUCTOR

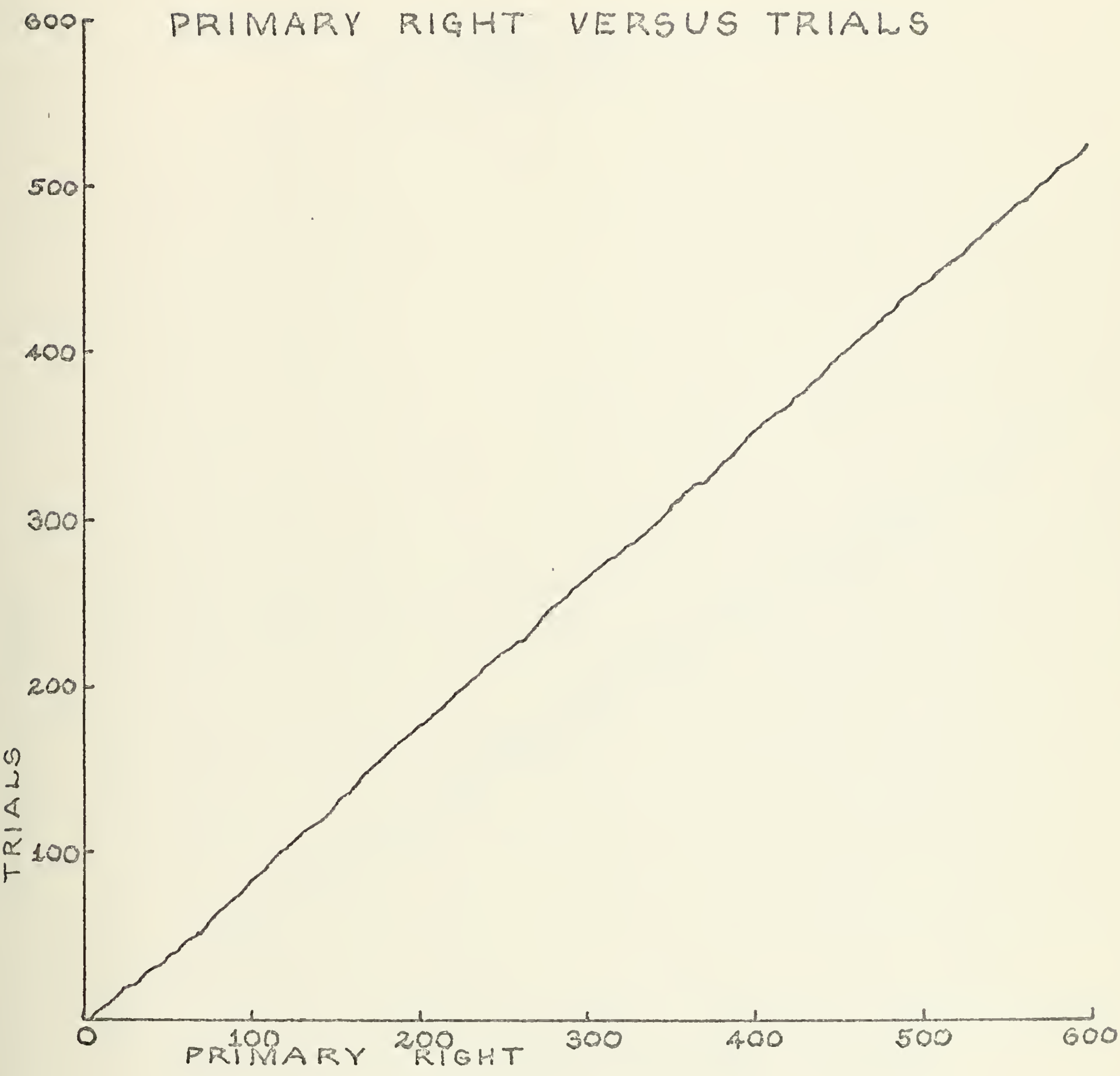


Figure 11

AVERAGE STUDENT--4000 HOUR INSTRUCTOR

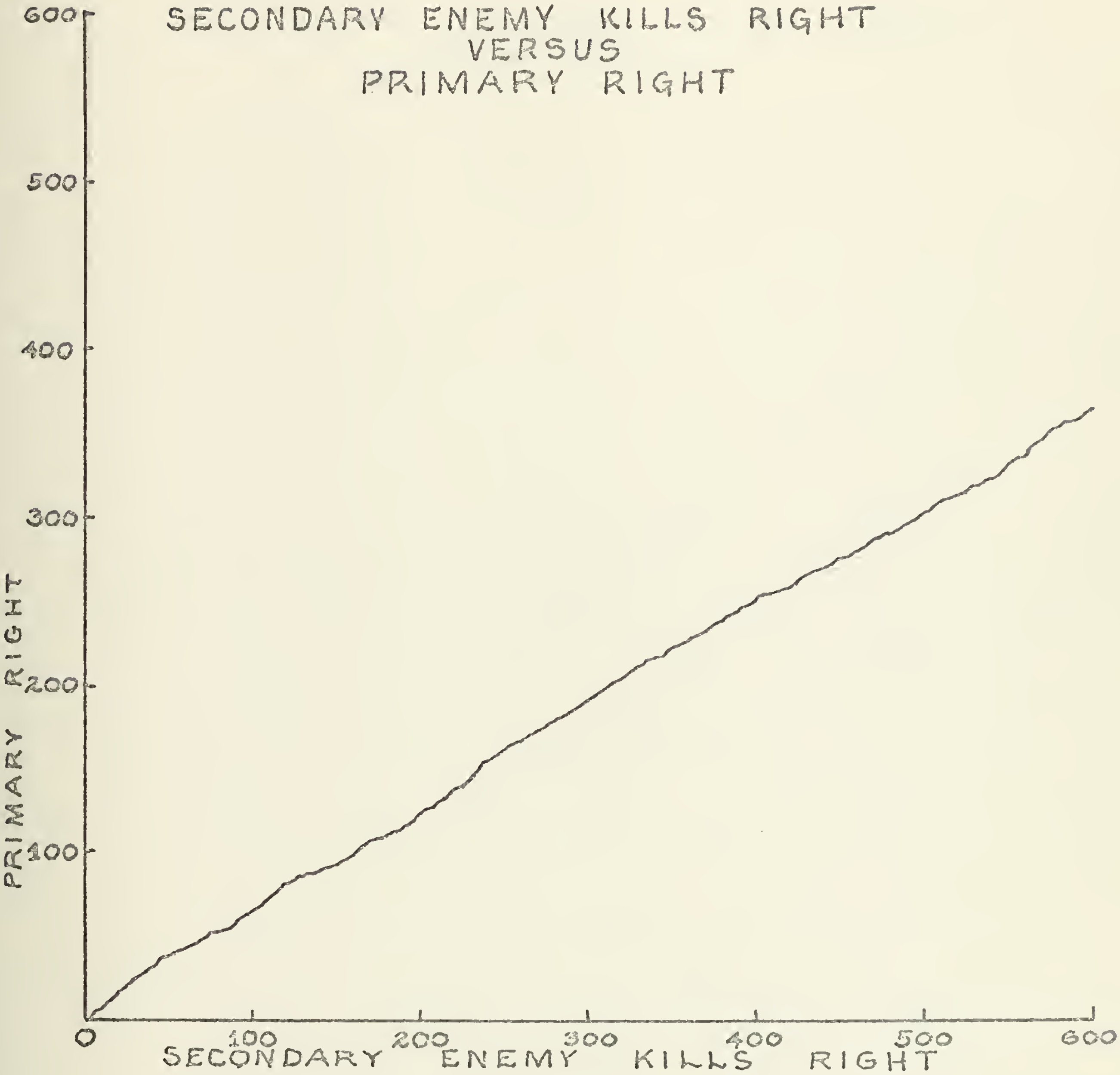


Figure 12

AVERAGE STUDENT-4000 HOUR INSTRUCTOR

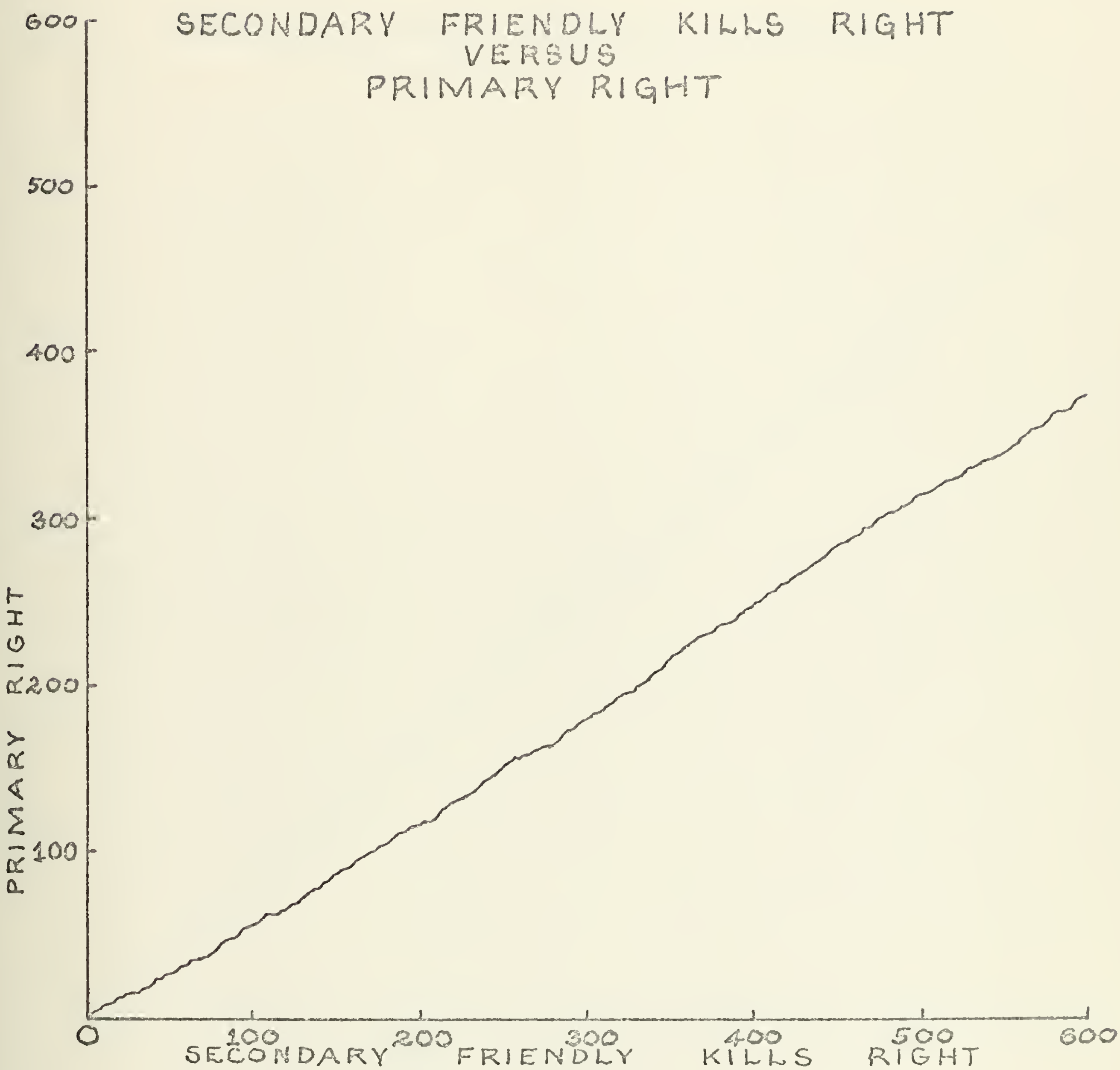


Figure 13

AVERAGE STUDENT-300 MISSION INSTRUCTOR

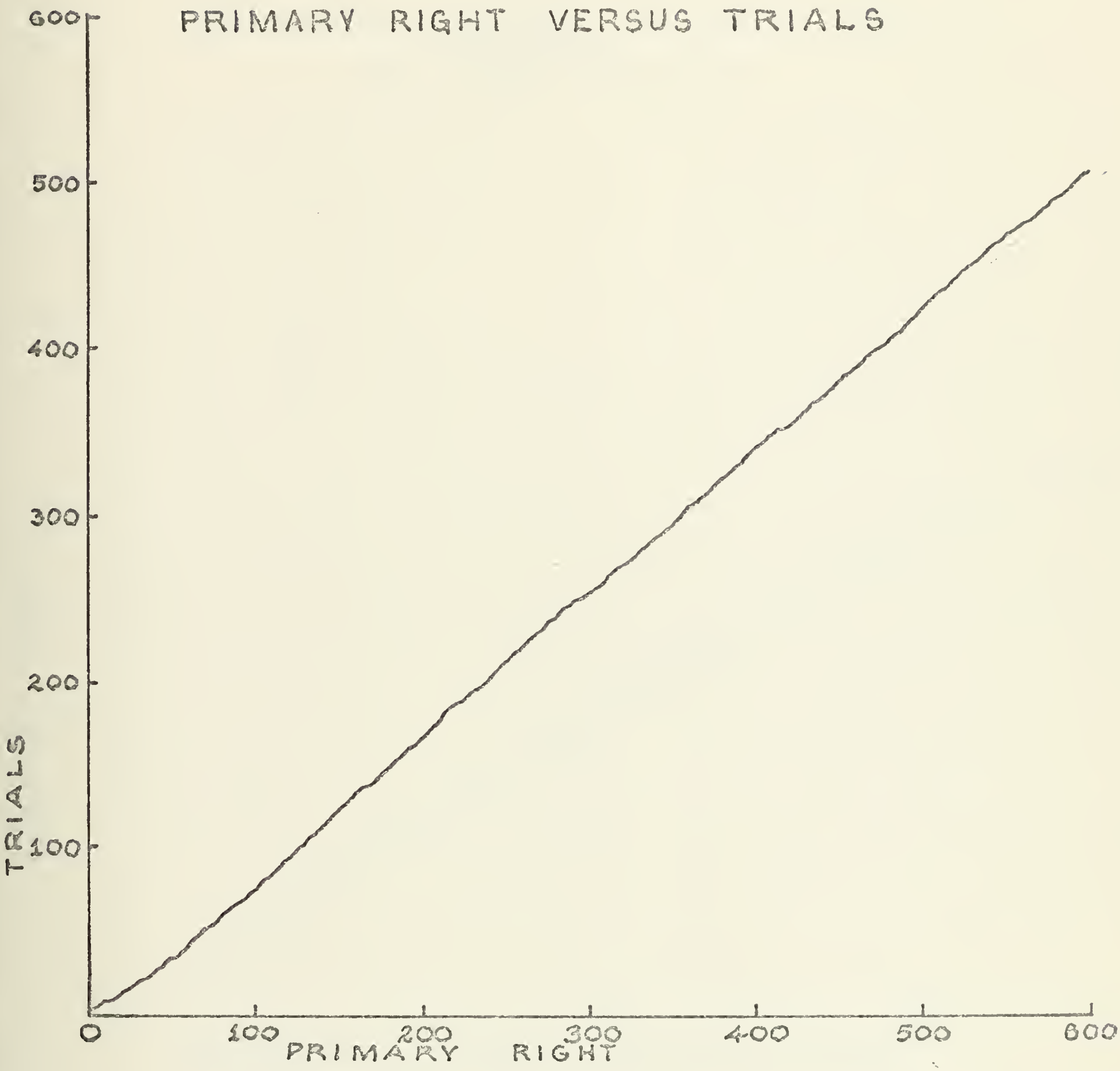


Figure 14

AVERAGE STUDENT-300 MISSION INSTRUCTOR

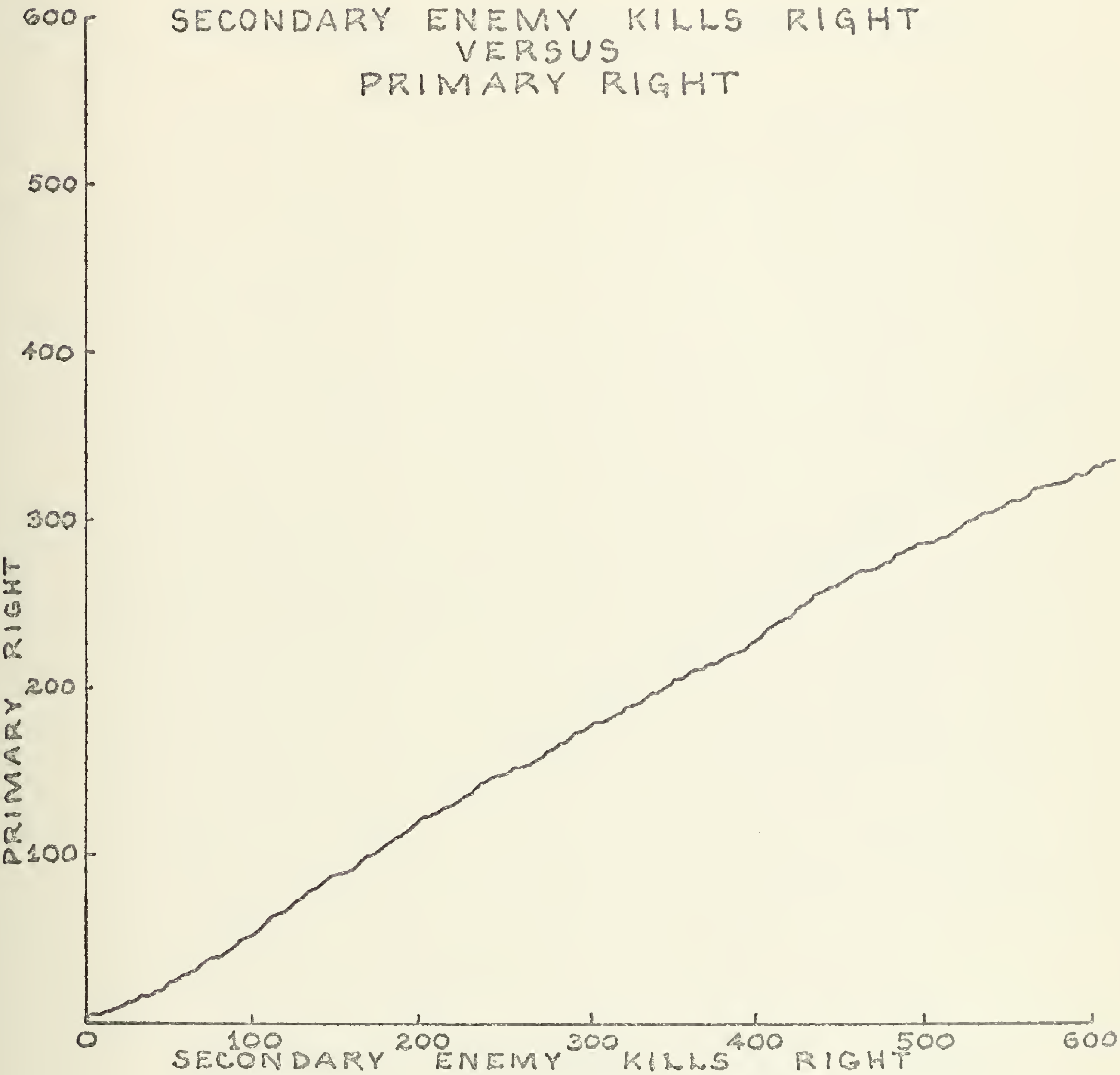
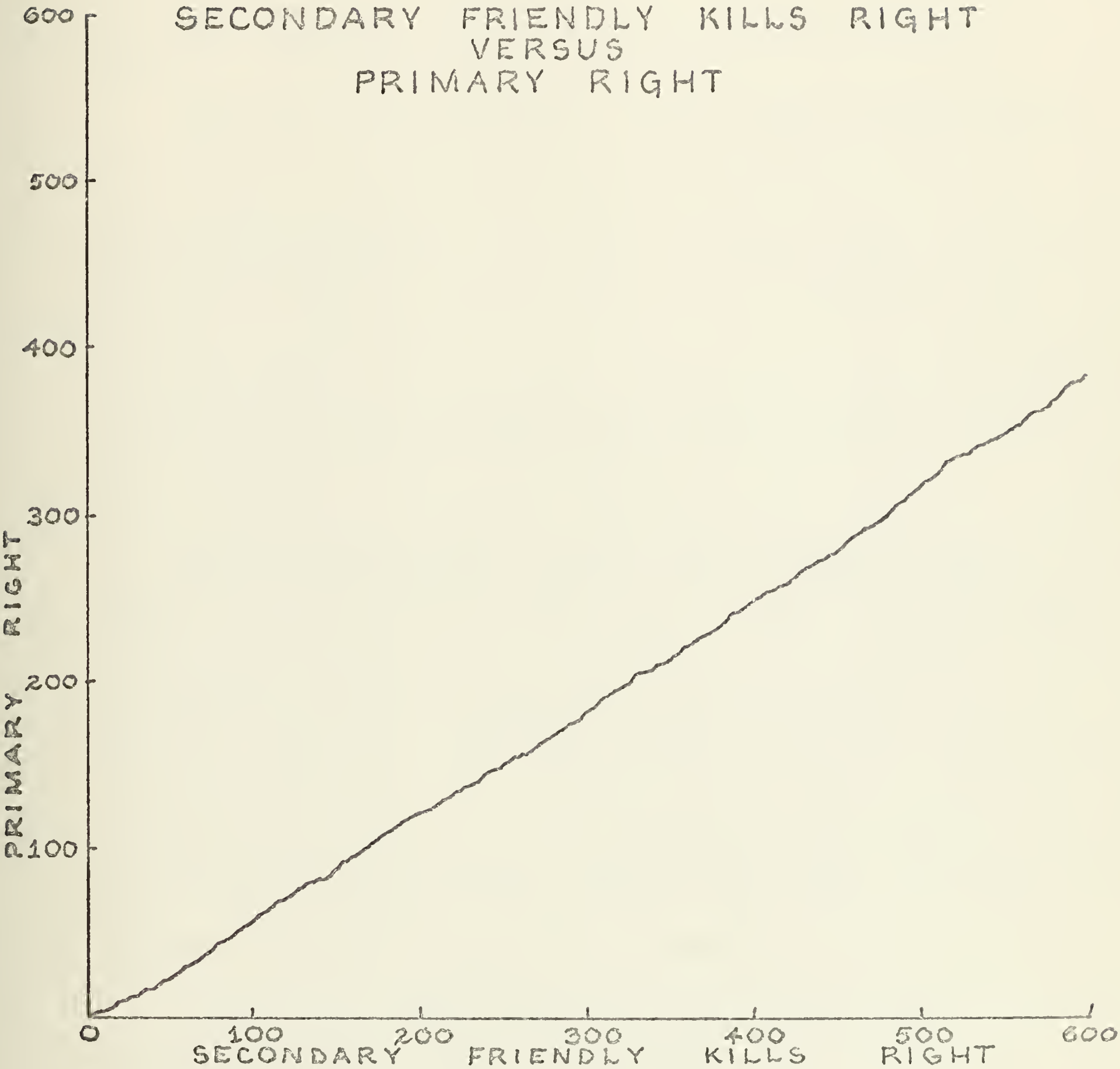


Figure 15

AVERAGE STUDENT-300 MISSION INSTRUCTOR



It took 40 additional trials for the correct primary decision percentage to reach 90% of the final percentage. The secondary enemy and friendly kill decision percentages took 137 and 56 additional correct primary decisions, respectively, to reach 90% of their final percentages.

With the Commander instructor, the first correct primary decision was attained after 221 trials, the first correct secondary enemy kill and friendly kill decisions after 194 and 177 correct primary decisions, respectively. After 47 additional trials, the correct primary decision percentage reached 90% of the final. The secondary enemy and friendly kill decision percentages reached 90% of the final percentages after 40 and 111 additional correct primary decisions, respectively.

With the 4000-plus hour instructor, the first correct primary decision was reached after 199 trials, the first correct secondary enemy and friendly kill decisions coming after 172 and 161 correct primary decisions, respectively. Forty-eight additional trials were needed to attain 90% of the final correct primary tactical decision percentage, 32 and 72 additional correct primary decisions were needed to attain 90% of the final correct secondary enemy and friendly decision percentages.

The 300-plus mission instructor used 206 trials before the first correct primary tactical decision was reached, 149 and 177 correct primary decisions before the first correct secondary enemy and friendly kill decisions, respectively. Eighty-three additional trials were needed to attain 90% of the final correct primary tactical decision percentage,

Table 16

BEGINNING STUDENT-AVERAGE INSTRUCTOR

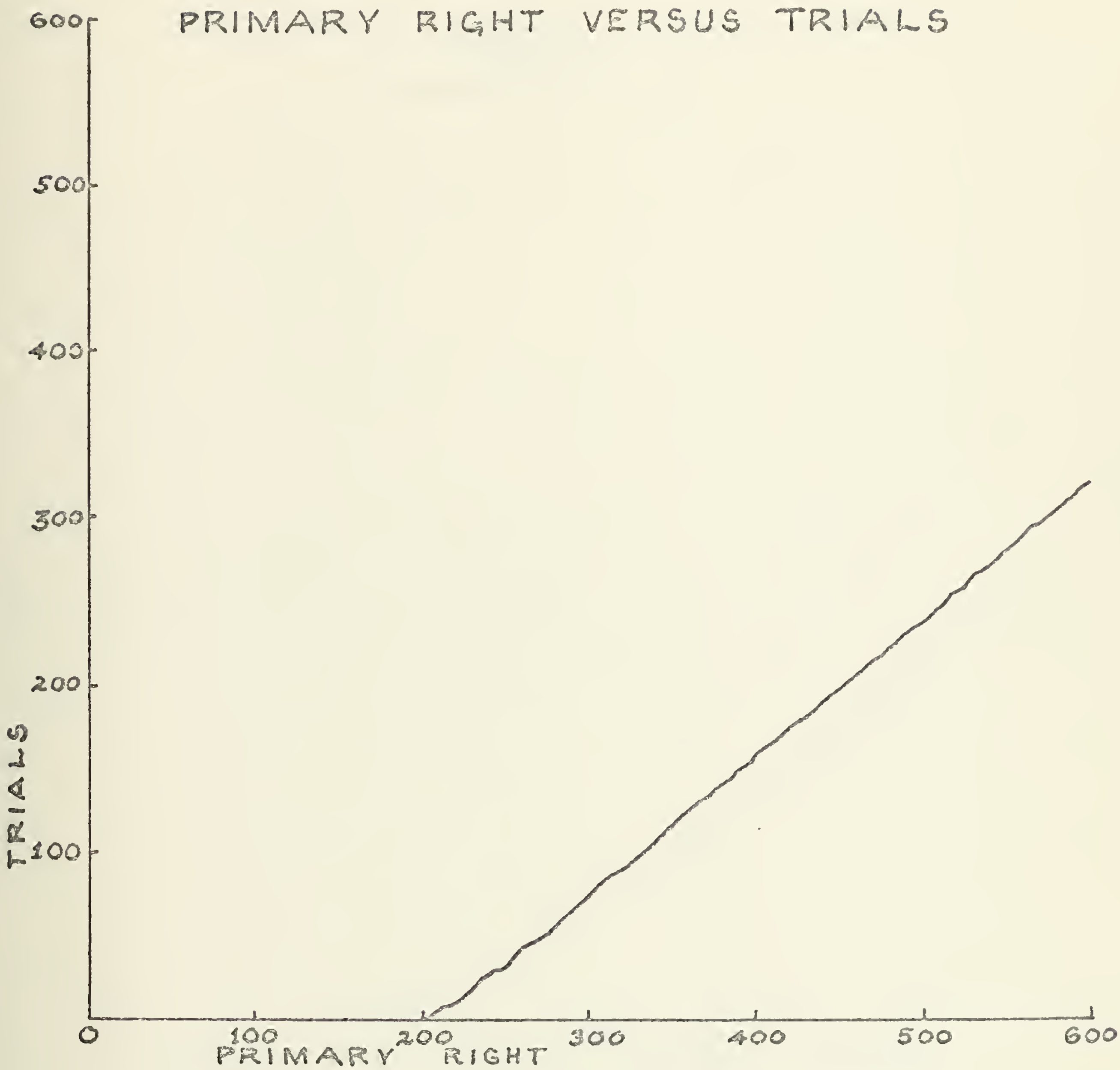


Figure 17

BEGINNING STUDENT-AVERAGE INSTRUCTOR

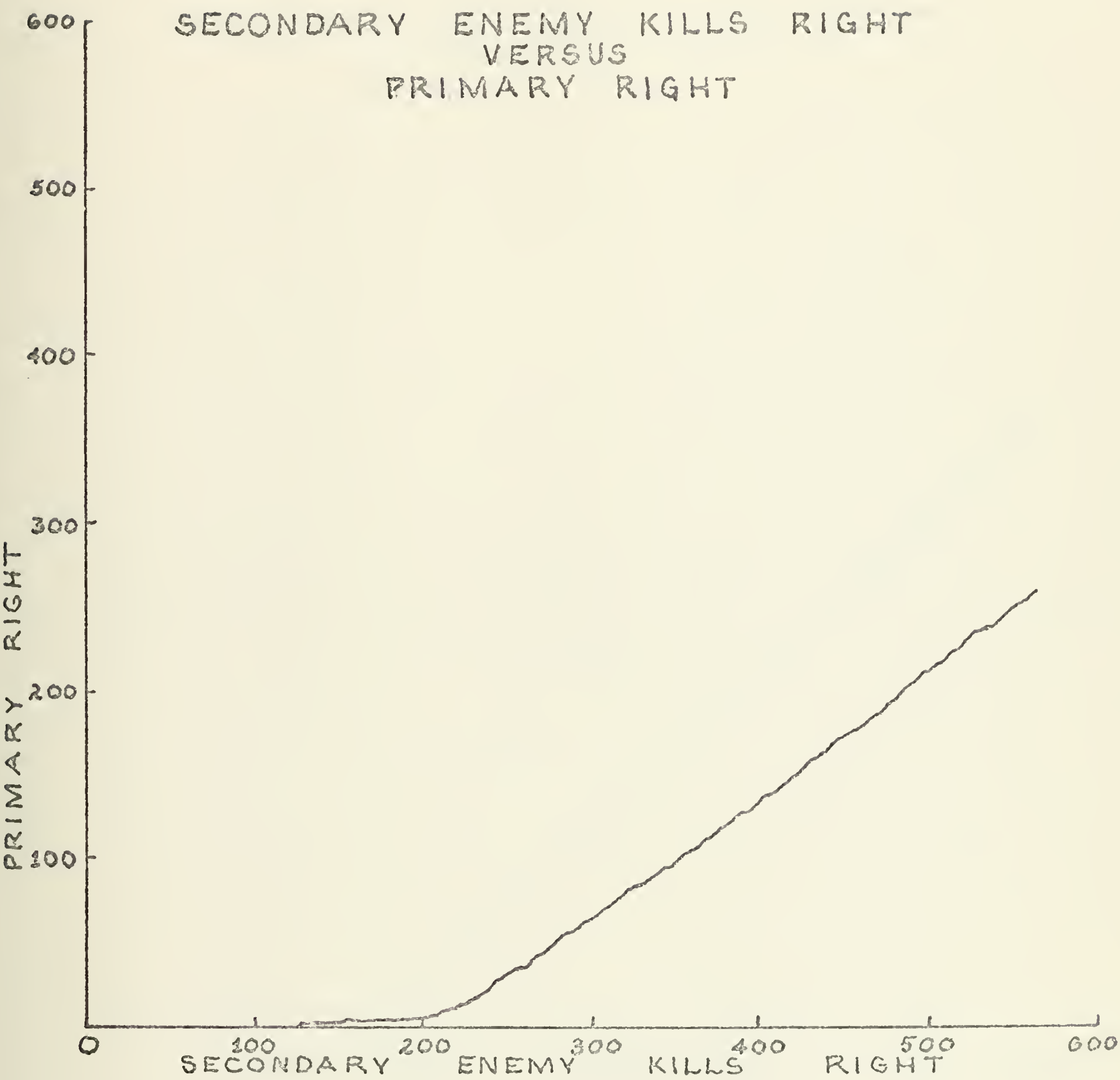


Figure 18

BEGINNING STUDENT-AVERAGE INSTRUCTOR

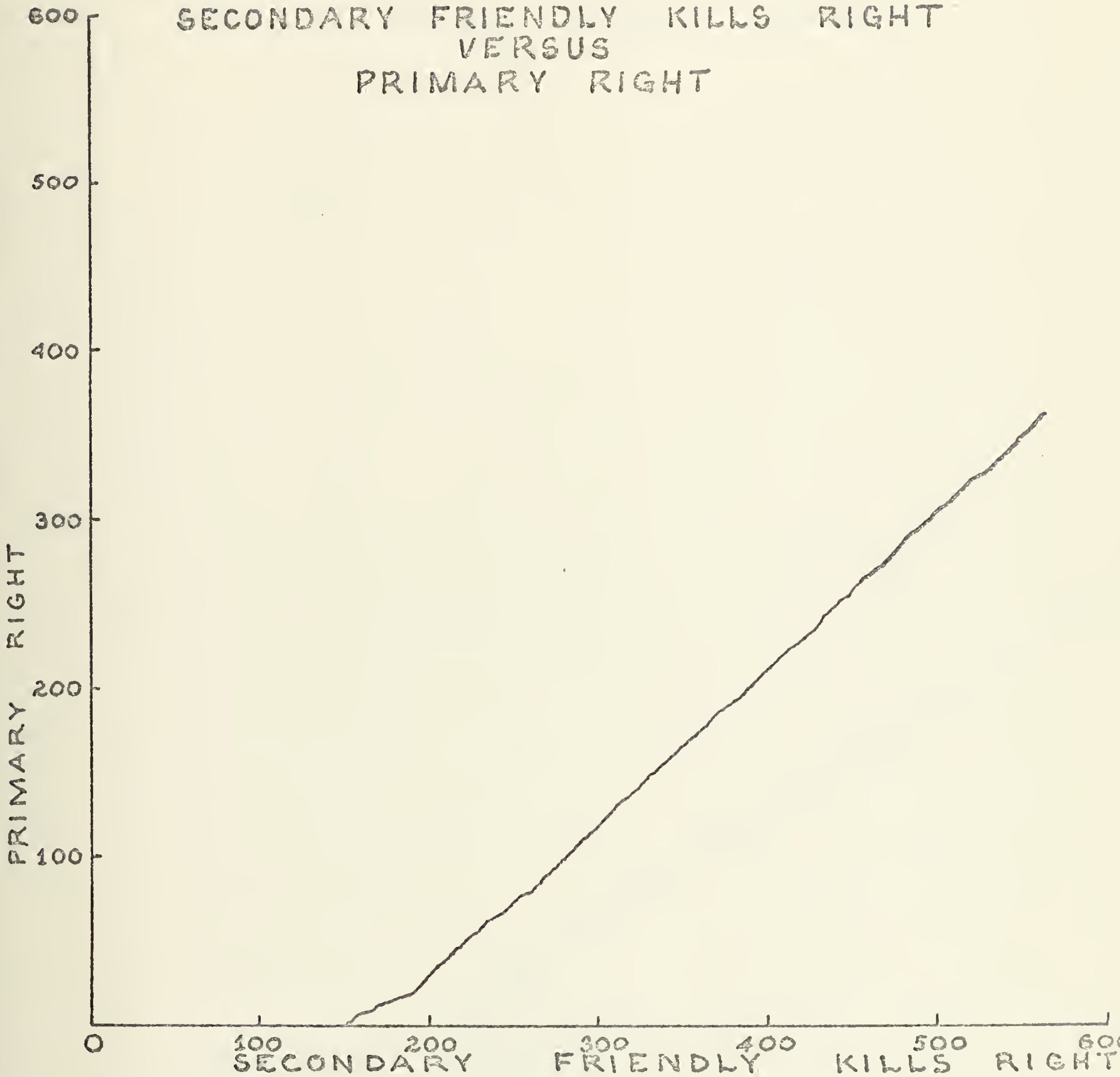


Figure 19

BEGINNING STUDENT-CDR INSTRUCTOR

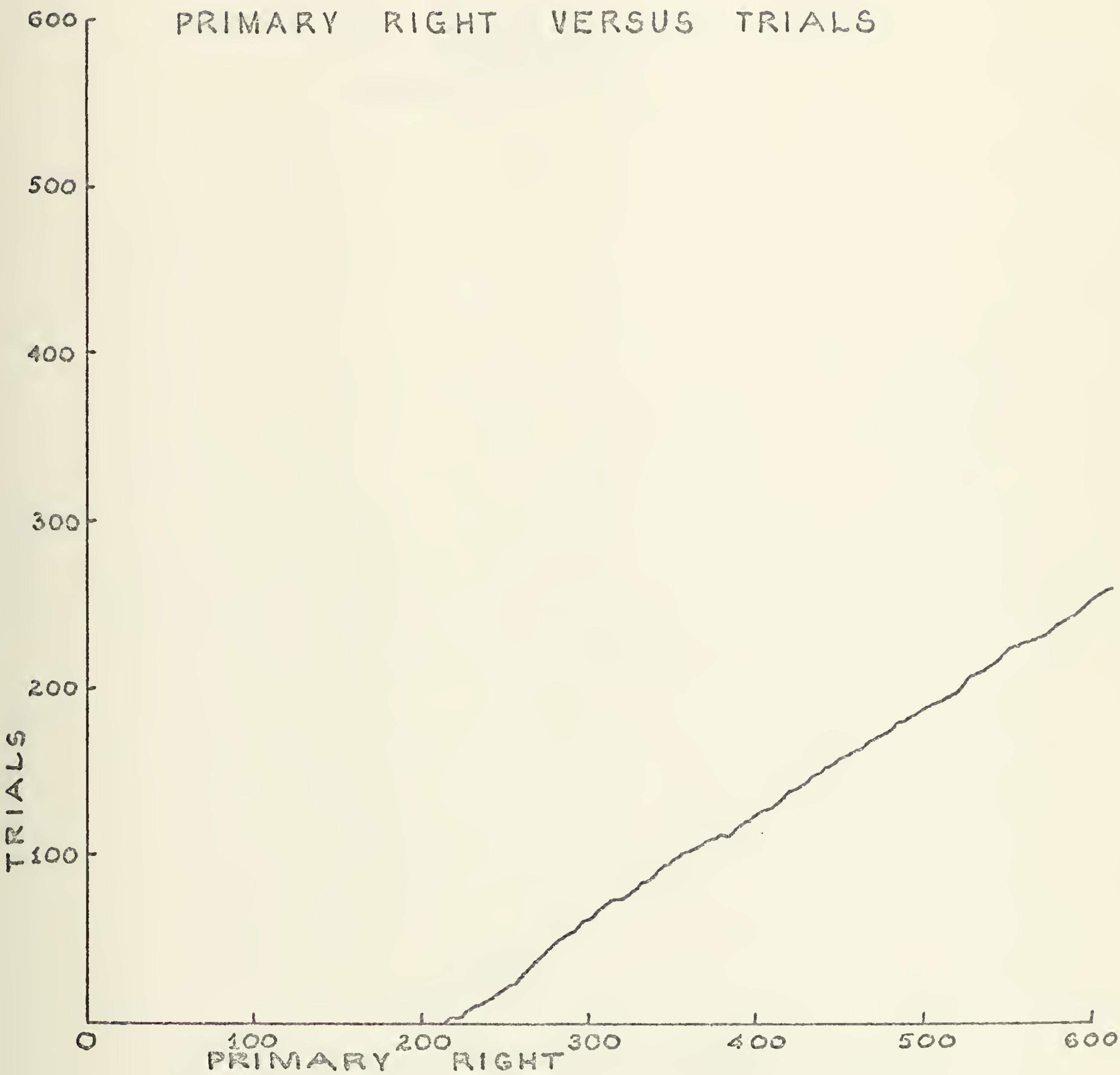


Figure 20

BEGINNING STUDENT-CDR INSTRUCTOR

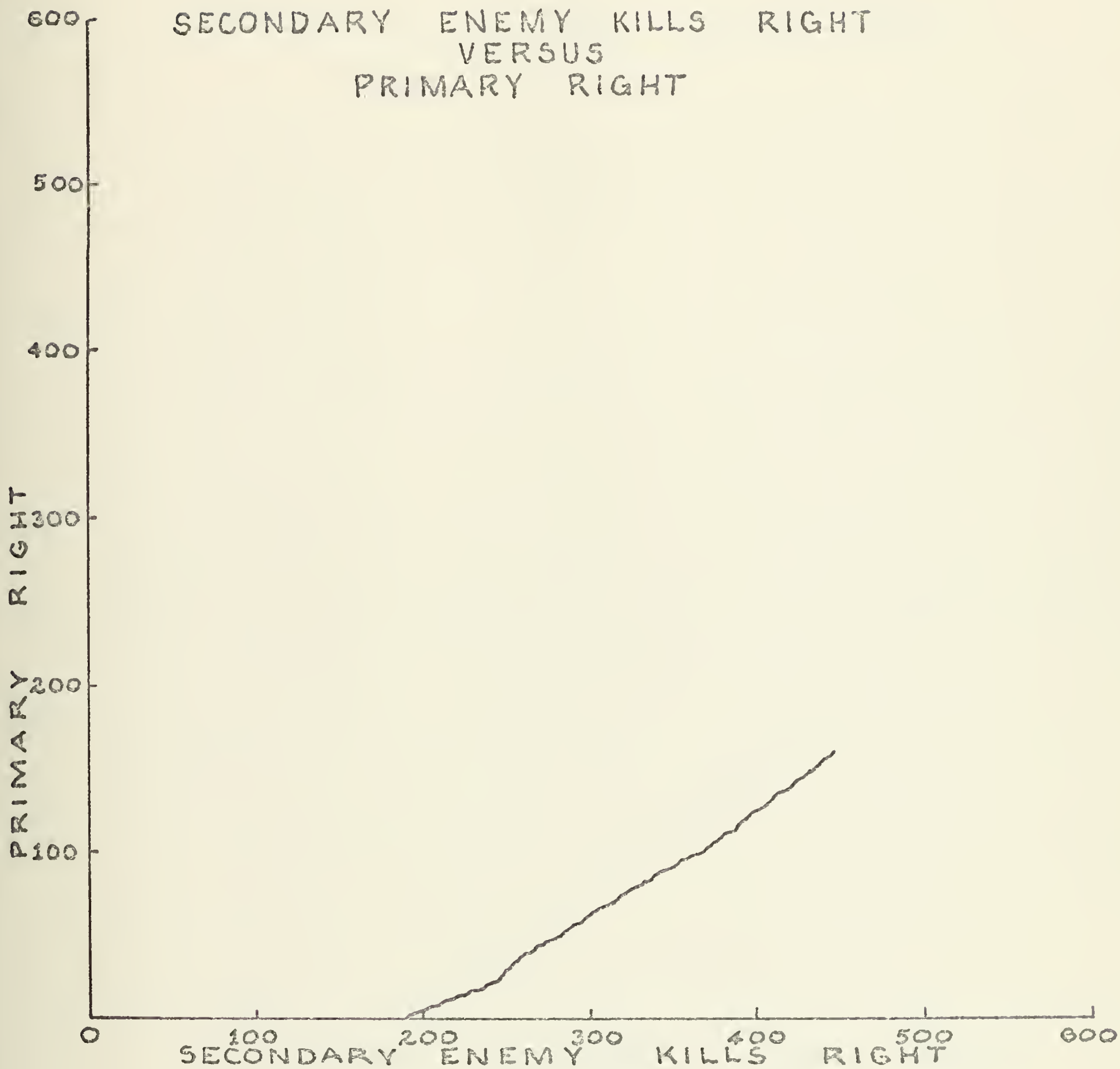


Figure 21

BEGINNING STUDENT-CDR INSTRUCTOR

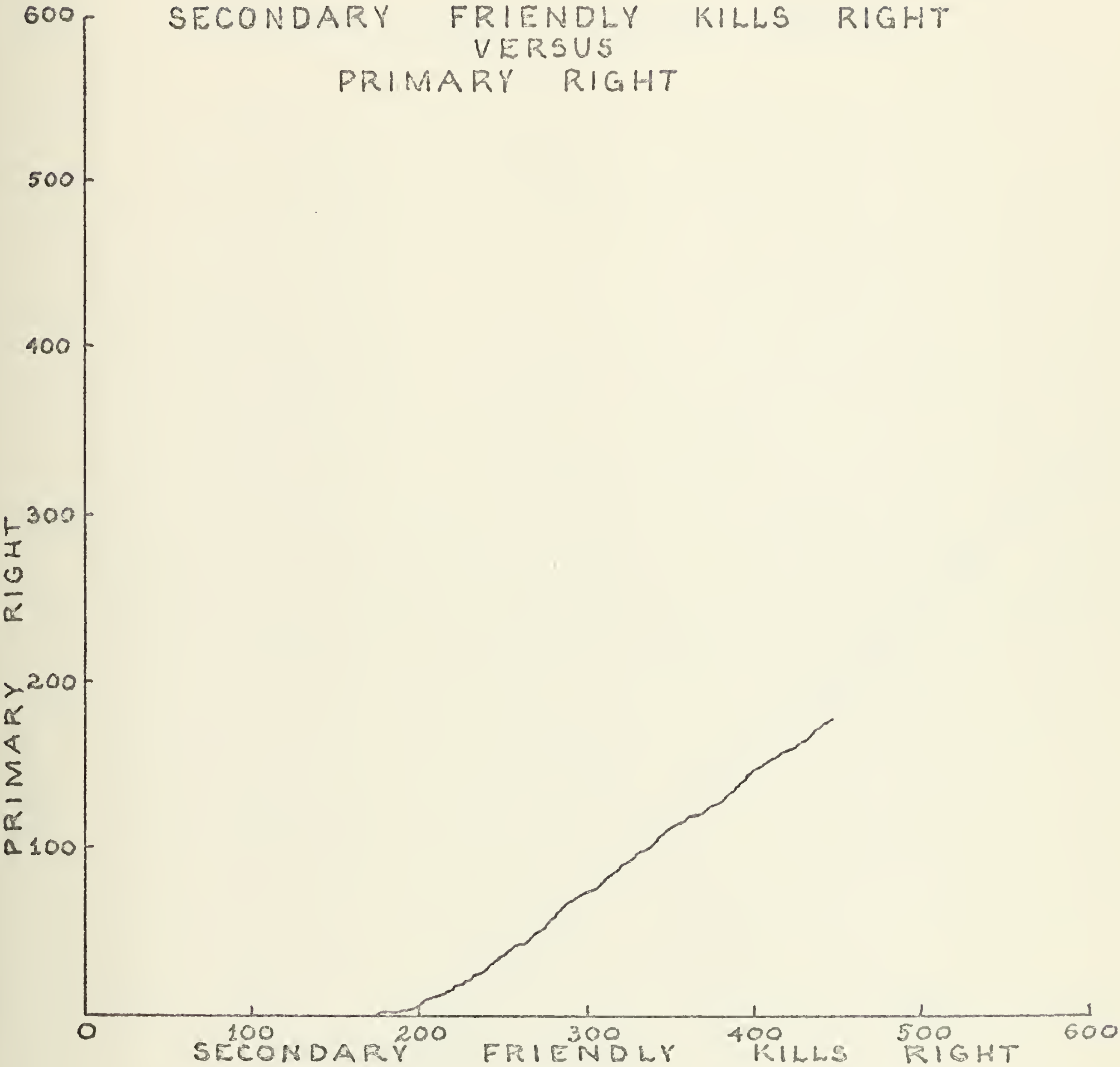


Figure 22

BEGINNING STUDENT-4000 HOUR INSTRUCTOR

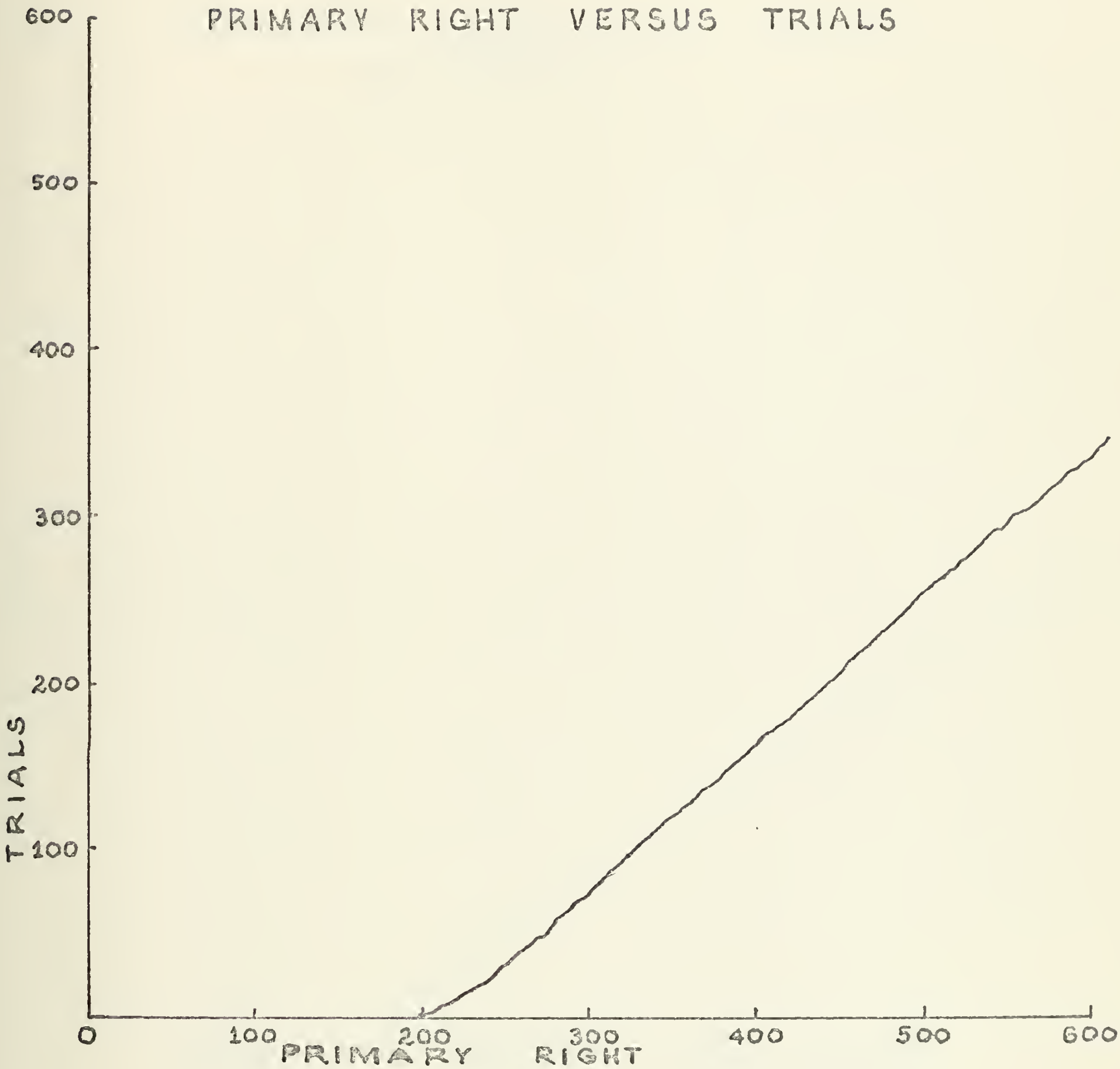


Figure 23

BEGINNING STUDENT-4000 HOUR INSTRUCTOR

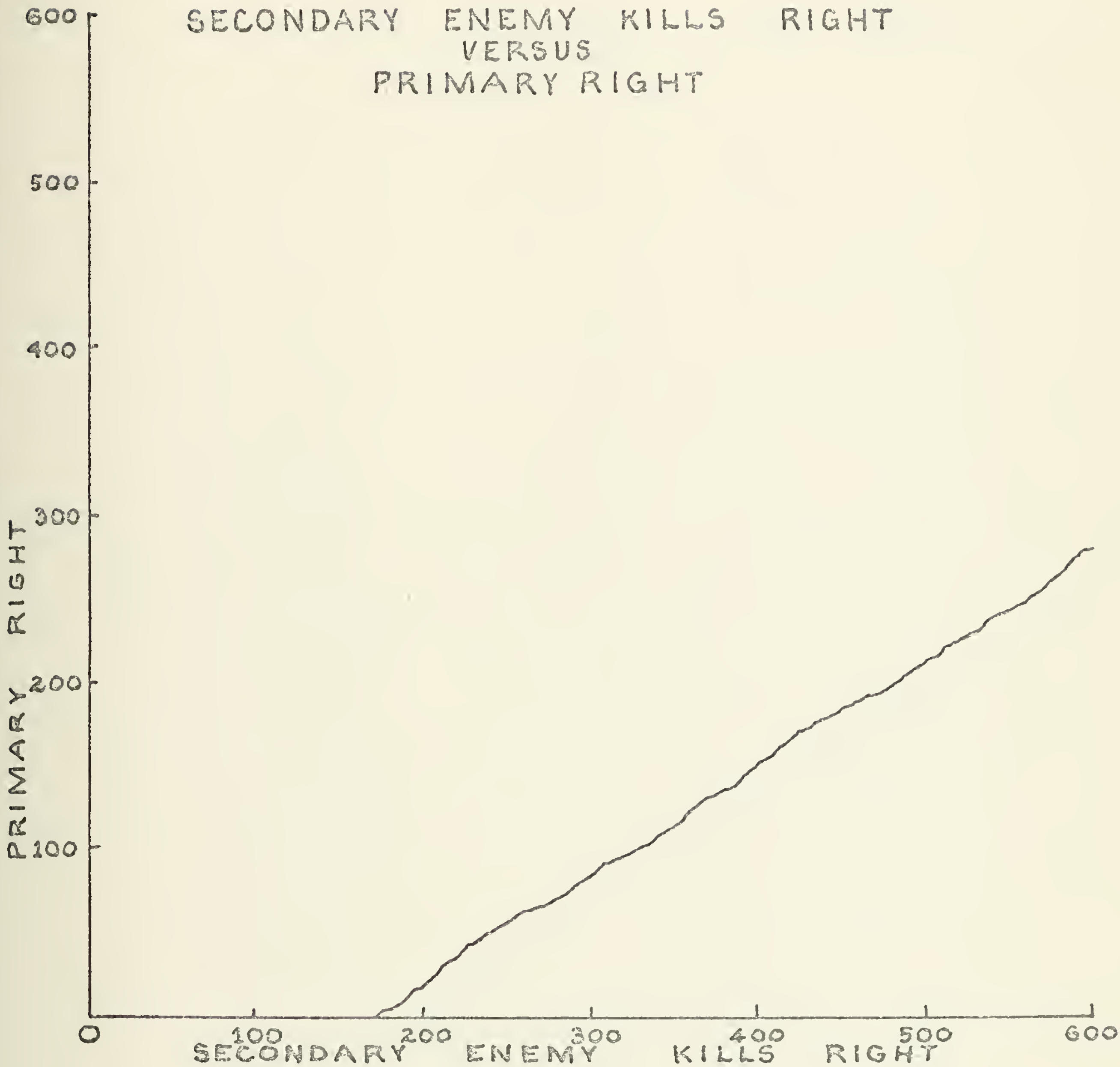


Figure 24

BEGINNING STUDENT-4000 HOUR INSTRUCTOR

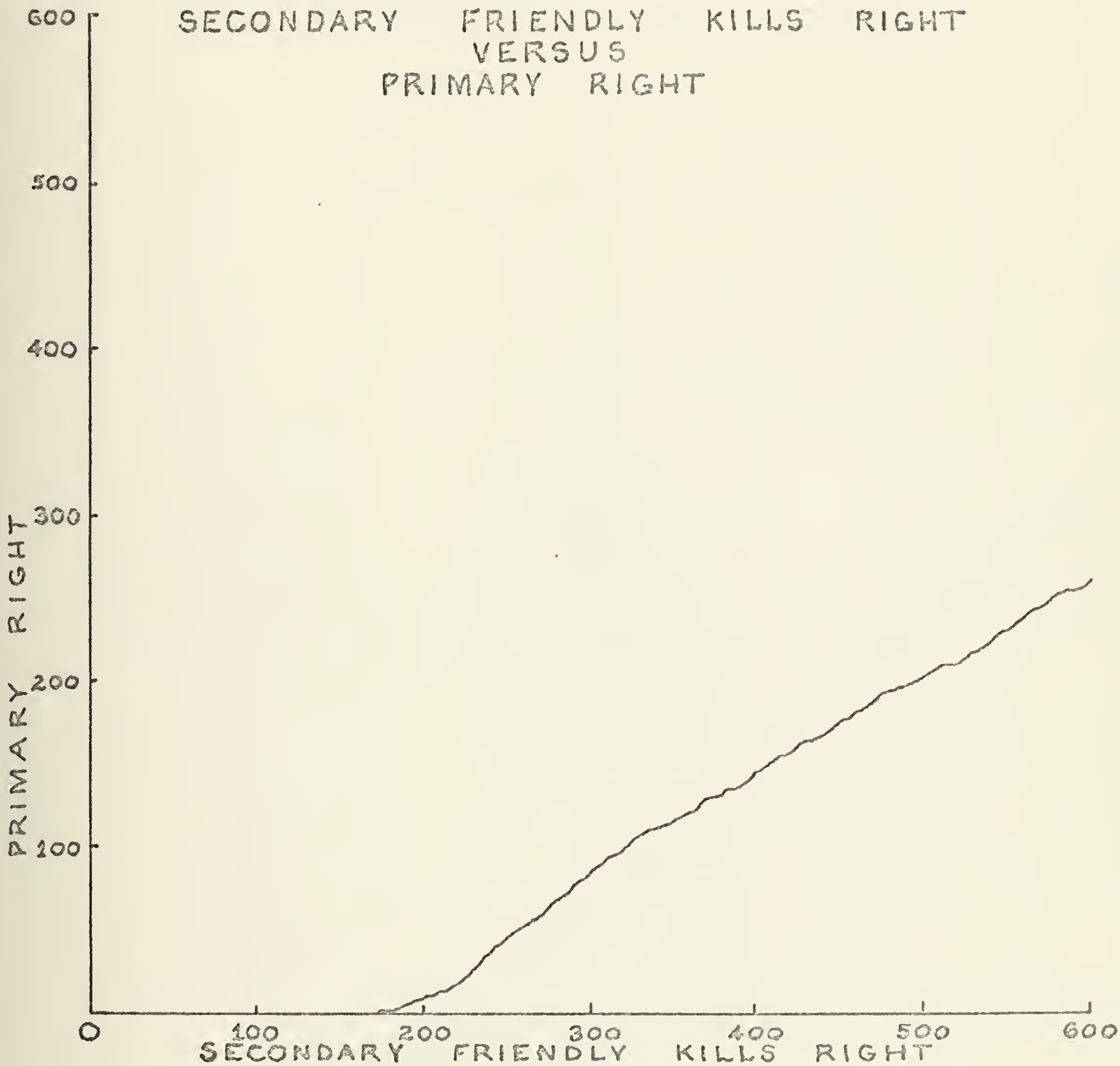


Figure 25

BEGINNING STUDENT-300 MISSION INSTRUCTOR

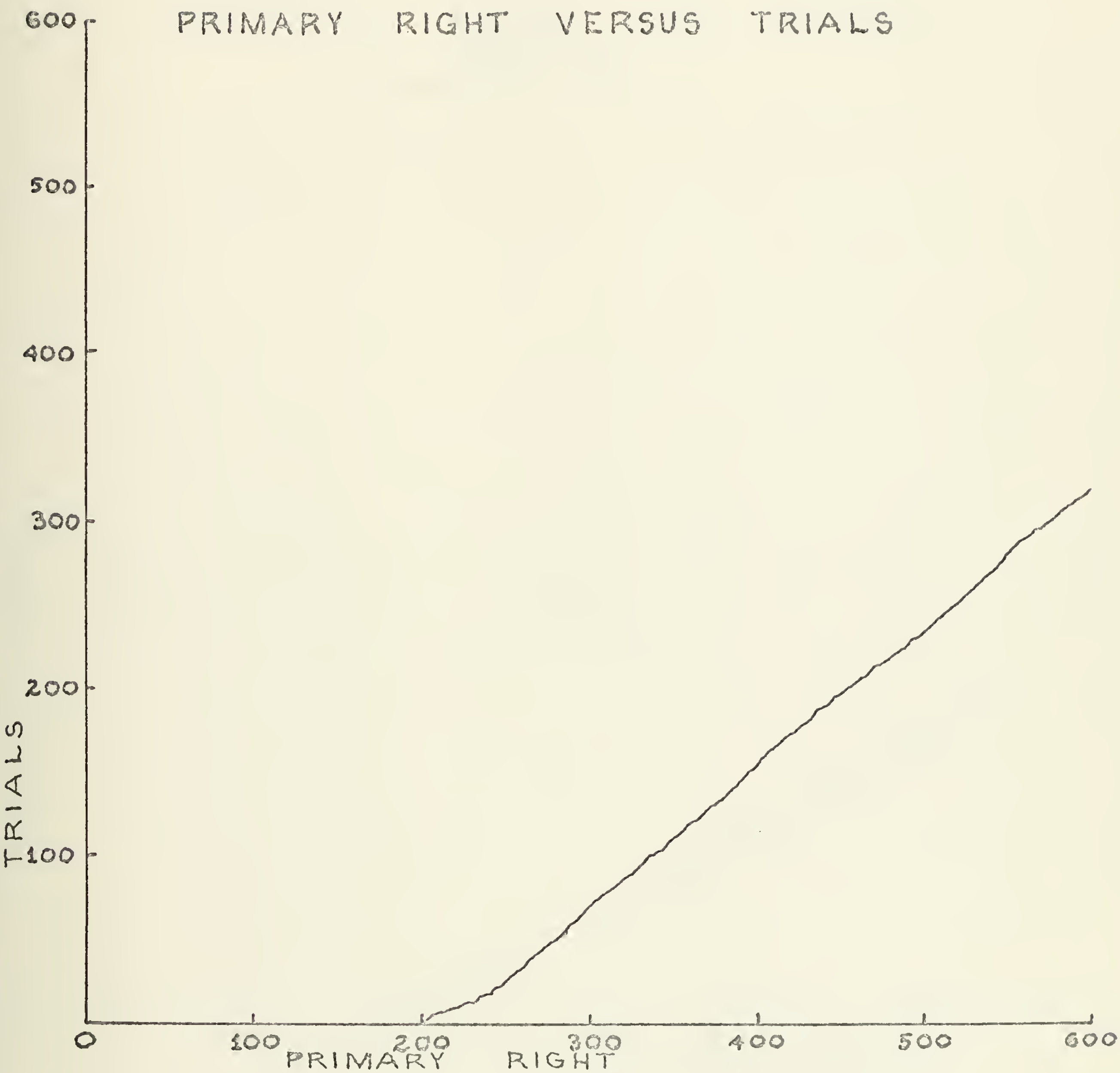


Figure 26

BEGINNING STUDENT-300 MISSION INSTRUCTOR

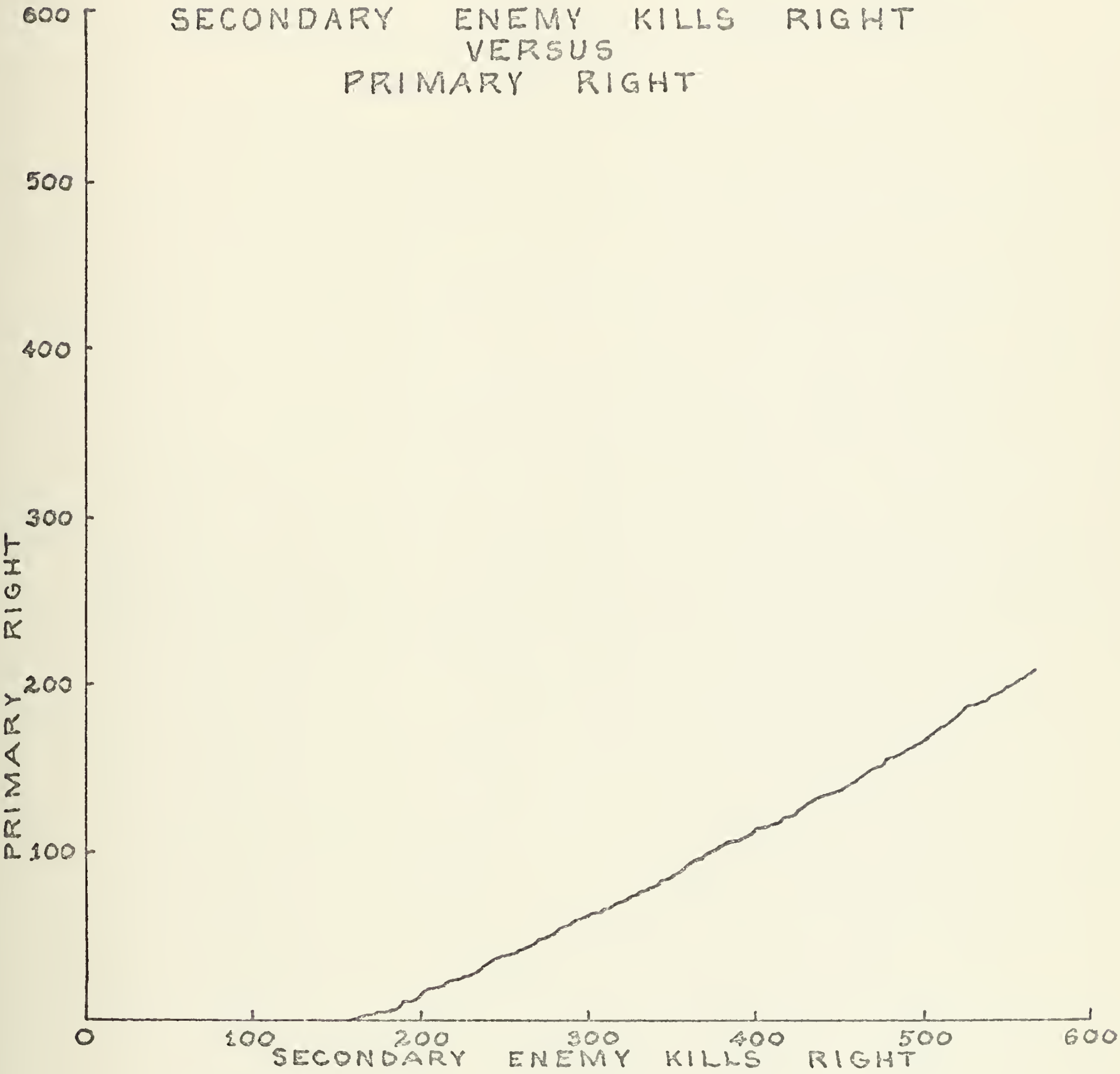
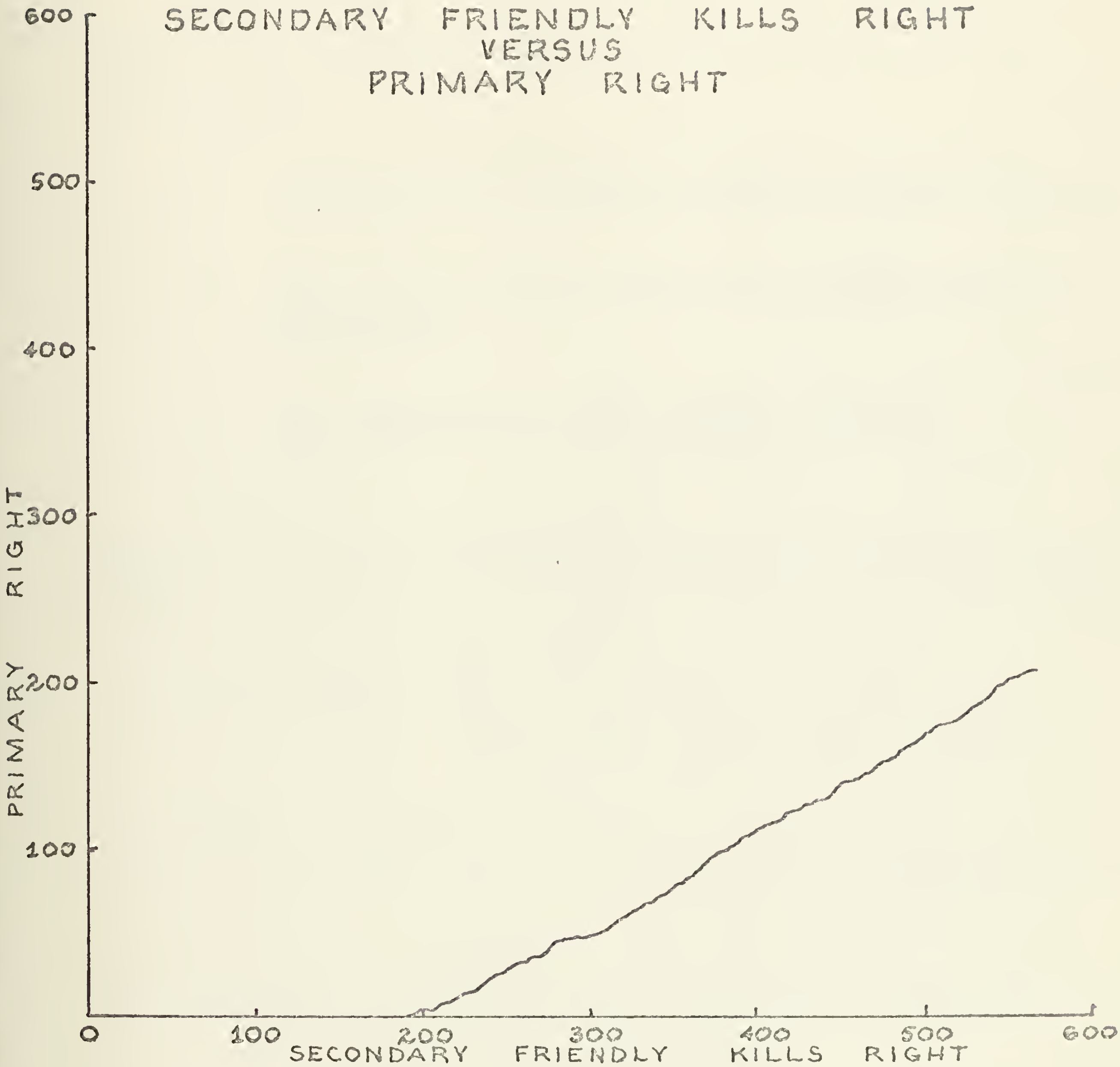


Figure 27

BEGINNING STUDENT-300 MISSION INSTRUCTOR



104 and 225 additional correct primary decisions to reach 90% of the first correct secondary enemy and friendly kill percentages, respectively.

In comparison with the runs and graphs for the average pilot as student, three significant points stand out (See Figures 4-15, 16-27 and Table VIII):

(1) The beginner requires a lengthy time to attain even one correct decision, no matter what decision is being considered.

(2) After a correct decision, the beginner in general, needs a longer learning time to reach the average pilot's degree of sophistication.

(3) Once this degree of sophistication is reached, the beginner and average pilot are nearly identical in behavior.

In essence, the beginner is, indeed, a beginner. In fact, the beginner could even be considered the average pilot three hundred trials younger. The panel of aviators considered the beginner as analogous to the beginning aviation student: the long, flat, error period being as in his ground and basic schooling where the basic ideas and guidance are implanted; the learning period as the time when a student's motor skills are honed to the point that unencumbered mental integration of the entire flight situation is developed - the transition from flight student to a full fledged Naval aviator; and the more constant, steady period as the reliable activity of an experienced pilot.

As can be seen in Table VI, discrepancies do appear between instruction as in the average pilot student runs. Whether these discrepancies are significant or not is a matter of conjecture. In light

of the data analysis showing little correlation of biographical features with decisions reached, this question of significant instructor differences must remain unanswered unless further research is conducted.

C. THE ARTIFICIAL INTELLIGENCE QUESTION

Does this program and its resulting runs fall into the classification of artificial intelligence? Taking the program in its entirety, one finds that it does analyze its own performances, does diagnose its failures and does make changes that enhance its future effectiveness and performance. This behavior, if witnessed in a human being, would be called intelligent behavior. Therefore, by previously cited criteria [8, 11] this program does, indeed, fall into the classification of artificial intelligence.

VI. CONCLUSION

In summation, the low correlations between the biographical factors of rank, hours and combat missions and the decisions made in the evaluation of an air-to-air combat situation is disconcerting. The explanation that the standardization of training and flight procedures may account for this lack of relationship seems of doubtful validity to the author. The one area showing any hint of a relationship is rank and the prediction of friendly kills. Still, the coefficient of correlation is weak (See Table II).

The multiple correlations between the decisions and situational variables are moderately low to moderately high, varying from .3378 to .8193. The lack of any high correlation coefficient values may be due to randomness in the primary and secondary decision making among the pilots. It may also be due to the failure of the multiple regression to capture the decision making policy either due to missing variables or a failure to capture a non-linear relationship with a linear function. Still, in the case of the average pilot, the equations produced from the multiple regression predicted 757 correct primary decisions out of 900, 548 correct enemy kill decisions out of 757, and 714 correct friendly kill decisions out of 757. This indicates a rather adequate capturing of the average pilot's decision policy. The relatively low correlation statistics may, in this light, be misleading.

On the average, the variables most influencing a pilot in reaching a tactical decision of the types shown in Figures I and II appear to be MPG and danger, the least important being fuel remaining and rules of engagement (See Table VI). The fact that fuel remaining is considered least important while MPG, a function of fuel remaining, is considered most important indicates the necessity of considering MPG as a separate, though not necessarily independent, function of range and fuel remaining.

A study by Rigney and De Bow [6] has shown that 63 Combat Information Center watch officers considered range and enemy course (heading) as the most important air raid threat variables. Although the watch officer's situation is radically different from that of the pilot, the fact that range is an argument of the MPG function and course is an argument of the danger function is interesting, especially in light of the fact that the watch officer does not consider fuel.

The most important variables considered in making the secondary enemy kill decisions are the tactical decision reached, fuel-remaining, and rules of engagement (See Table VI). The least important are MPG and the number of enemy. An interesting reversal of importance can be witnessed in MPG being considered most important in reaching a tactical decision and least important in the secondary enemy kill decision. Also, the two least important variables in the tactical decision are second and third in importance in predicting this secondary enemy kill decision.

Number of enemy, tactical decision and speed seem most important in predicting pilots' friendly kill expectancies. Least important in this prediction are MPG and range. Again, in comparison with the tactical decision, MPG is seen to switch roles. Also noticeable is the number of enemy's rise to most important while, in the enemy kill decision, it is the next to least important. The three decisions appear to be, in fact, three separate decisions, the first (primary tactical) affecting the others (enemy kills and friendly kills) but neither of the latter two affecting each other.

Looking at the pilots individually, and within their biographical groups, differences do appear to exist in how they reach their tactical decisions. But these differences do not appear to be correlated with rank, hours or missions but are, rather, insignificant random perturbations. Secondary decisions show little cross-group variation (See Table VI and Appendix G).

The artificial intelligence program does appear to show adaptive learning behavior when the program is taken in its entirety. The behavior of the program can reasonably be termed intelligent. Therefore, one could safely say that the variables and factors influencing an air-to-air combat evaluation can, for the most part, be quantified and utilized in an artificial intelligence application of air-to-air combat decision making policies.

VII. CRITICAL EVALUATION OF THE STUDY

Several pertinent critical comments pertaining to this study are:

(1) The group of 36 pilots from which data were gathered is too small to allow any justifiable generalization to Navy pilots in general. Consequently, as a result of this small size, any statistics and findings generated may not be representative of Navy pilots in general.

Granted, no generalizations about all Navy fighter pilots can be safely made from these findings. An appreciably larger sample is required. Still, the sample did cover 2304 separate evaluations. Any generalizations drawn do apply, at least, to the group and situations studied.

(2) The assumption that certain factors, such as rank, primary decisions, and rules of engagement, can be quantified is questionable, i.e., does a Commander possess five times the amount of rank as an Ensign?

Granted, especially in the area of attempting to quantify a variable such as rules of engagement. Still, quantifying rank and placing the decisions on a continuum are not necessarily unrealistic. Perhaps a better substitute for rank would be lineal number and the subjects should be asked to give a number value on a decision continuum; the relationships between primary decisions as presented not necessarily being linear.

(3) The situational variables such as bearing, heading, fuel states, range and number of enemy are not, in reality, restricted to only two states.

Granted, however, questionnaire size limitations enforces such a binary state. Still, a better data base could result from a broader representation of the situational variables.

(4) In light of the low biographical-decision correlation, how can one assume that expertise is proportional to a biographical attribute?

The question of expertise, although interesting, is essentially a moot one. The only true criteria of expertise in the situation would deal with the results of actual air-to-air combat. Since the number of people with this kind of expertise is small and not

available to the researcher, "experts" were picked by the previously described method. Whether, as a result of learning, the student has developed into a better or worse fighter pilot cannot be determined is irrelevant. What is relevant is whether or not the student approaches the standards of his declared "expert" instructor.

(5) It appears unrealistic to ask a pilot with no combat experience to evaluate a combat situation.

Although seemingly unrealistic on the surface, the armed forces do require a person with no combat experience to make an evaluation of an actual combat situation. However, the person normally has undergone extensive and realistic simulated combat training. All of the 36 pilots studied have undergone such training. An interesting note is the similarity in decisions between the no combat group and Lieutenant Commander group which has an average combat total of over 160 missions (See Table VI and Appendix G).

(6) The artificial intelligence program is simply a model of a situation-instructor-student interaction.

Whether the artificial intelligence program is a model or does not detract from the fact that it meets the stated criteria of artificial intelligence.

(7) Certain factors may be used for predictors several times in the same equation, such as MPG, range and fuel, raising the multiple correlation accordingly.

Granted, but the apparent separation of seemingly related functions in the ranking scales (See Table VI and Appendix G) and the experience of the panel of aviators does not make this practice appear unrealistic.

(8) The student's confidence level increases with success but does not decrease with failure, a situation that may be unrealistic.

Granted, however, when a decreasing confidence level was implemented, the modification factor in the beginning stages grew so large as to cause erratic and rapid convergence to the instructor's coefficients. Overcoming this problem, however, would not be difficult.

VIII. CONTINUATION OF THE STUDY

More data are desperately needed before any of the results uncovered can be safely generalized to Navy pilots in general. Likewise, more situations are needed for presentation to the subjects. A factor indicating a consideration of the enemy's plight must also be sought. For example, variables indicative of the friendly airplane pointing at the enemy or number of friendlies could be considered.

The computer graphics field is a likely method to use in future data collection and in developing real time interactive artificial intelligence applications. For example, the cathode ray tube screen could easily be configured to resemble a cluster of instruments and radar scope. The situation would then be presented on the scope via simulated radar images, digital readings on the instrument and appropriate character generation. Via random number generation a multitude of situations could be presented to the subject. Teletype or light pen input would increase the subject's interaction and speed of response, allowing several hundred responses in the space of an hour. Real time data collection and analysis could produce desired statistics and multiple regression equations on demand. In the same manner, by using the artificial intelligence program described in this study, the human could take over the role of instructor with appropriate modifications for response collection and analysis. By not utilizing the modification subroutines,

the human could take the place of the student, his coefficients being evaluated and graded by the instructor, followed by a response such as "You are not emphasizing your fuel state enough" or "You are neglecting your range consideration." The training, selection and research possibilities in this area are boundless, limited only by the researcher's imagination. Through this kind of work, the fighter pilot may become less of an enigma, less of a superman; more of a human.

APPENDIX A

QUESTIONNAIRE

1. a) Relative position (range and bearing) of the enemy aircraft to the strike force. ________

   b) Type enemy aircraft suspected or known. ________

   c) I cannot choose between them ________

2. a) Composition of enemy force--number of raid(s) and number of aircraft in each raid. ________

   b) Number of assigned TARCAP aircraft available. ________

   c) I cannot choose between them. ________

3. a) Range of enemy aircraft to the strike group. ________

   b) Speed (absolute) of the enemy aircraft. ________

   c) I cannot choose between them. ________

4. a) Relative position (range and bearing) of the enemy aircraft to the strike group. ________

   b) Range of enemy aircraft to the strike group. ________

   c) I cannot choose between them. ________

5. a) Type enemy aircraft suspected or known. ________

   b) Capabilities and systems operability of your own aircraft (e.g., fuel state, number of missiles, etc.). ________

   c) I cannot choose between them. ________

6. a) Speed (absolute) of the enemy aircraft. ________

   b) Altitude of the enemy aircraft. ________

   c) I cannot choose between them. ________

7. a) Anti-aircraft, including surface to air missile (SAM), activity in your immediate area. ________

b) Capabilities and systems operability of your own aircraft (e.g., fuel state, number of missiles, etc.). ________

c) I cannot choose between them. ________

8. a) Altitude of the enemy aircraft ________

b) Composition of enemy force--number of raid(s) and number of aircraft in each raid. ________

c) I cannot choose between them. ________

9. a) Number of assigned TARCAP aircraft available. ________

b) Bearing of the enemy aircraft from yourself. ________

c) I cannot choose between them. ________

10. a) Bearing of the enemy aircraft from yourself. ________

b) Anti-aircraft, including surface to air missile (SAM), activity in your immediate area. ________

c) I cannot choose between them. ________

11. a) Relative position (range and bearing) of the enemy aircraft to the strike force. ________

b) Rate of closure of enemy aircraft to yourself. ________

c) I cannot choose between them. ________

12. a) Rate of closure of enemy aircraft to yourself. ________

b) Composition of enemy force--number of raid(s) and number of aircraft in each raid. ________

c) I cannot choose between them. ________

13. a) Number of assigned TARCAP aircraft available. ________

b) Range of enemy aircraft to the strike force. ________

c) I cannot choose between them. ________

14. a) Speed (absolute) of the enemy aircraft. ________

b) Relative position (range and bearing) of the enemy aircraft to the strike force. ________

c) I cannot choose between them. ________

15. a) Capabilities and systems operability of your own aircraft (e.g., fuel state, number of missiles, etc.). ________

b) Range of enemy aircraft to the strike force. ________

c) I cannot choose between them. ________

16. a) Speed (absolute) of the enemy aircraft. ________

b) Type enemy aircraft suspected or known. ________

c) I cannot choose between them. ________

17. a) Anti-aircraft, including surface to air missile (SAM), activity in your immediate area. ________

b) Altitude of the enemy aircraft. ________

c) I cannot choose between them. ________

18. a) Capabilities and systems operability of your own aircraft (e.g., fuel state, number of missiles, etc.). ________

b) Altitude of the enemy aircraft. ________

c) I cannot choose between them. ________

19. a) Type of enemy aircraft suspected or known. ________

b) Anti-aircraft, including surface to air missile (SAM), activity in your immediate area. ________

c) I cannot choose between them. ________

20. a) Relative position (range and bearing) of the enemy aircraft to the strike force. ________

b) Composition of enemy forces--number of raid(s) and number of aircraft in each raid. ________

c) I cannot choose between them. ________

21. a) Rate of closure of enemy aircraft to yourself. ________

b) Range of enemy aircraft to the strike force. ________

c) I cannot choose between them. ________

22. a) Number of assigned TARCAP aircraft available. ________

b) Relative position (range and bearing) of the enemy aircraft to the strike force. ________

c) I cannot choose between them. ________

23. a) Capabilities and systems operability of your own aircraft (e.g., fuel state, number of missiles, etc.). ________

b) Speed (absolute) of the enemy aircraft. ________

c) I cannot choose between them. ________

24. a) Capabilities and systems operability of your own aircraft (e.g., fuel state, number of missiles, etc.). ________

b) Number of assigned TARCAP aircraft available. ________

c) I cannot choose between them. ________

25. a) Composition of enemy forces--number of raid(s) and number of aircraft in each raid. ________

b) Bearing of the enemy aircraft from yourself. ________

c) I cannot choose between them. ________

26. a) Type enemy aircraft suspected or known. ________

b) Bearing of the enemy aircraft from yourself. ________

c) I cannot choose between them. ________

27. a) Rate of closure of enemy aircraft to yourself. ________

b) Anti-aircraft, including surface to air missile (SAM), activity in your immediate area. ________

c) I cannot choose between them. ________

28. a) Anti-aircraft, including surface to air missile (SAM), activity in your immediate area. ________

b) Range of enemy aircraft to the strike force. ________

c) I cannot choose between them. ________

29. a) Altitude of the enemy aircraft. ________

b) Type of enemy aircraft suspected or known. ________

c) I cannot choose between them. ________

30. a) Altitude of the enemy aircraft. ________

b) Number of assigned TARCAP aircraft available. ________

c) I cannot choose between them. ________

31. a) Bearing of the enemy aircraft from yourself.. ______

b) Capabilities and system operability of your own aircraft (e.g., fuel state, number of missiles, etc.). ______

c) I cannot choose between them. ______

32. (a) Composition of enemy force--number of raid(s) and number of aircraft in each raid. ______

b) Type of enemy aircraft suspected or known. ______

c) I cannot choose between them. ______

33. a) Bearing of the enemy aircraft from yourself. ______

b) Rate of closure of enemy aircraft to yourself. ______

c) I cannot choose between them. ______

34. a) Composition of enemy force--number of raid(s) and number of aircraft in each raid. ______

b) Anti-aircraft, including surface to air missiles (SAM), activity in your immediate area. ______

c) I cannot choose between them. ______

35. a) Rate of closure of enemy aircraft to yourself. ______

b) Capabilities and system operability of your own aircraft (e.g., fuel state, number of missiles, etc.). ______

c) I cannot choose between them. ______

36. a) Number of assigned TARCAP aircraft available. ______

b) Speed (absolute) of the enemy aircraft. ______

c) I cannot choose between them. ______

37. a) Speed (absolute) of the enemy aircraft. ________

b) Anti-aircraft, including surface to air missiles (SAM), activity in your immediate area. ________

c) I cannot choose between them. ________

38. a) Range of enemy aircraft to the strike force. ________

b) Altitude of the enemy aircraft. ________

c) I cannot choose between them. ________

39. a) Type enemy aircraft suspected or known. ________

b) Number of assigned TARCAP aircraft available. ________

c) I cannot choose between them. ________

40. a) Altitude of the enemy aircraft. ________

b) Bearing of the enemy aircraft from yourself. ________

c) I cannot choose between them. ________

41. a) Relative position (range and bearing) of the enemy aircraft to the strike force. ________

b) Capabilities and systems operability of your own aircraft (e.g., fuel state, number of missiles, etc.). ________

c) I cannot choose between them. ________

42. a) Speed (absolute) of the enemy aircraft. ________

b) Rate of closure of enemy aircraft to yourself. ________

c) I cannot choose between them. ________

43. a) Anti-aircraft, including surface to air missile (SAM), activity in your immediate area. ________

b) Number of assigned TARCAP aircraft available. ________

c) I cannot choose between them. ________

44. a) Anti-aircraft, including surface to air missile (SAM), activity in your immediate area. ________

b) Relative position (range and bearing) of the enemy aircraft to the strike force. ________

c) I cannot choose between them. ________

45. a) Range of enemy aircraft to the strike force. ________

b) Bearing of the enemy aircraft from yourself. ________

c) I cannot choose between them. ________

46. a) Rate of closure of enemy aircraft to yourself. ________

b) Altitude of the enemy aircraft. ________

c) I cannot choose between them. ________

47. a) Capabilities and systems operability of your own aircraft (e.g., fuel state, number of missiles, etc.). ________

b) Composition of enemy force--number of raid(s) and number of aircraft in each raid. ________

c) I cannot choose between them. ________

48. a) Range of enemy aircraft to the strike force. ________

b) Composition of enemy force--number of raid(s) and number of aircraft in each raid. ________

c) I cannot choose between them. ________

49. a) Bearing of the enemy aircraft from yourself. ________

b) Relative position (range and bearing) of the enemy aircraft to the strike force. ________

c) I cannot choose between them. ________

50. a) Bearing of the enemy aircraft from yourself. ________

b) Speed (absolute) of the enemy aircraft. ________

c) I cannot choose between them. ________

51. a) Range of enemy aircraft to the strike force. ________

b) Type enemy aircraft suspected or known. ________

c) I cannot choose between them. ________

52. a) Type enemy aircraft suspected or known. ________

b) Rate of closure of enemy aircraft to yourself. ________

c) I cannot choose between them. ________

53. a) Altitude of the enemy aircraft. ________

b) Relative position (range and bearing) of the enemy aircraft to the strike force. ________

c) I cannot choose between them. ________

54. a) Composition of enemy force--number of raid(s) and number of aircraft in each raid. ________

b) Speed (absolute) of the enemy aircraft. ________

c) I cannot choose between them. ________

55. a) Number of assigned TARCAP aircraft available. ________

b) Rate of closure of enemy aircraft to yourself. ________

c) I cannot choose between them. ________

APPENDIX B

PILOTS RESPONDING TO MAIL-OUT QUESTIONNAIRE

	Rank	Hours	Missions
1.	Commander	4500	70
2.	Commander	4000	143
3.	Commander	3500	240
4.	Commander	3300	354
5.	Lieutenant Commander	3450	200
6.	Lieutenant Commander	3200	300
7.	Lieutenant Commander	3200	140
8.	Lieutenant Commander	3000	218
9.	Lieutenant Commander	2700	172
10.	Lieutenant Commander	2655	130
11.	Lieutenant Commander	2550	113
12.	Lieutenant Commander	2500	11
13.	Lieutenant Commander	1900	150
14.	Lieutenant Commander	1600	200
15.	Lieutenant	2350	80
16.	Lieutenant	1800	249
17.	Lieutenant	1800	220
18.	Lieutenant	1750	70
19.	Lieutenant	1700	154
20.	Lieutenant	1700	75
21.	Lieutenant	1700	40
22.	Lieutenant	1500	200
23.	Lieutenant	1500	100
24.	Lieutenant	1400	150
25.	Lieutenant	1400	55
26.	Lieutenant	1300	90
27.	Lieutenant	1150	100
28.	Lieutenant	1100	130
29.	Lieutenant	1100	129
30.	Lieutenant	1050	0
31.	Lieutenant	1000	150
32.	Lieutenant	850	0
33.	Lieutenant	750	0
34.	Lieutenant	750	0
35.	Lieutenant	730	0
36.	Lieutenant (junior grade)	450	0

APPENDIX C

PANEL OF AVIATORS

Commander (selectee) - pilot, attack and fighter type aircraft experience; two instructor tours in the basic training command; one instructor tour with an attack Replacement Air Group; three combat tours in Southeast Asia; candidate for M.S. in Computer Science.

Lieutenant Commander - pilot; patrol type aircraft experience; one instructor tour in the basic training command; one combat tour in Southeast Asia; candidate for M.S. in Computer Science.

Lieutenant - pilot; attack type aircraft experience; one instructor tour in the Replacement Air Group; one combat tour in Southeast Asia; candidate for M.S. in Computer Science.

Lieutenant - Naval Flight Officer; experience as airborne intercept controller; one instructor tour in the basic training command teaching computer fundamentals; one combat tour in Southeast Asia; candidate for M.S. in Computer Science.

Lieutenant - Naval Flight Officer; experience as airborne intercept controller; one tour working on airborne computer display systems; one combat tour in Southeast Asia; candidate for M.S. in Computer Science.

APPENDIX D

DISCRIMINANT ANALYSIS FOR GROUPS DIFFERENTIATED BY BIOGRAPHICAL DATA

Significance Level of .05

Grouped by Rank:

Chi square = 14.0
Degrees of Freedom = 21
No significant differences between groups differentiated by rank.

Grouped by Hours:

Chi square = 24.0
Degrees of Freedom = 28
No significant difference between groups differentiated by flight hours.

Grouped by Missions:

Chi square = 44.0
Degrees of Freedom = 28
No significant difference between groups differentiated by combat missions.

APPENDIX E

SELECTED PREDICTOR EQUATION COEFFICIENTS

Primary Tactical Decision -- Corresponds to Prico Vector:

	Average Pilot	CDR	4000+	300+
1.	1.51835	1.23987	1.74982	1.12484
2.	-.00014	-.00005	-.00015	-.00005
3.	.3910	.05223	.03590	.05204
4.	.05065	.03086	.05952	.03043
5.	-.12239	-.07430	-.08141	-.06924
6.	.00352	.00223	.00132	.00440
7.	.00028	.00023	.00016	.00079
8.	8.24161	5.59970	4.11829	-3.22020

Secondary Enemy Kill Decision - Corresponds to Secoen Vector:

	Average Pilot	CDR	4000+	300+
1.	.82003	1.20750	.23976	1.06406
2.	.00034	.00018	.00038	.00024
3.	.02213	.05697	.05474	.01154
4.	.03087	.12087	-.01666	.18579
5.	.41223	.20282	.34197	.21952
6.	-.00281	-.00306	-.00242	-.00253
7.	-.00020	-.00001	.00013	-.00008
8.	-7.81100	-13.56913	27.20380	11.08119
9.	-.43846	-.66584	-.22533	-.57411

Secondary Friendly Kill Decision - Corresponds to Secofr Vector:

	Average Pilot	CDR	4000+	300+
1.	.56915	.39760	.74056	.17621
2.	-.00004	.00012	.00009	.00007
3.	-.00558	-.01702	-.01714	-.01947
4.	.08816	.18036	.08989	.30649
5.	-.09740	-.23837	-.25172	-.26590
6.	.00059	.00129	-.00023	.00278
7.	.00013	.00019	.00014	.00024
8.	3.26289	28.96692	25.10820	24.35280
9.	-.24901	-.32516	-.33688	-.28021

APPENDIX F

MEAN AND STANDARD DEVIATIONS OF DECISIONS MADE

Rank Group		Primary Decision	Enemy Kills	Friendly Kills
CDR	$\bar{X}$	1.95	1.40	.61
	SD	.82	1.09	1.01
LCDR	$\bar{X}$	1.96	.93	.32
	SD	.80	.99	.64
LT	$\bar{X}$	2.01	1.10	.18
	SD	.78	1.00	.48
LTJG	$\bar{X}$	2.16	.70	.08
	SD	.76	.75	.27
Hours Group				
4000+	$\bar{X}$	2.16	.83	.41
	SD	.80	.78	.55
4000	$\bar{X}$	1.83	1.44	.51
	SD	.79	1.15	.95
3000	$\bar{X}$	1.92	.96	.26
	SD	.79	.94	.61
2000	$\bar{X}$	2.07	1.04	.16
	SD	.96	1.06	.45
1000	$\bar{X}$	1.99	1.00	.26
	SD	.77	.84	.55
Mission Group				
300+	$\bar{X}$	1.74	1.56	.88
	SD	.92	1.02	1.28
300	$\bar{X}$	2.02	1.10	.19
	SD	.74	1.08	.53
200	$\bar{X}$	2.01	.96	.23
	SD	.80	1.01	.53
100	$\bar{X}$	2.01	1.10	.23
	SD	.80	1.04	.57
0	$\bar{X}$	1.97	1.07	.24
	SD	.75	.85	.52

$\bar{X}$ = arithmetic mean
SD = standard deviation

APPENDIX G

VARIABLE RANKINGS FOR HOUR AND MISSION GROUPS

HOUR GROUP:

Primary Tactical Decision

	4000+	3000-4000	2000-3000	1000-2000	0-1000
MPG	1	5	7	1	7
Danger	5	2	2	3	3
Speed	3	3	3	4	2
Range	4	1	1	6	1
Number of Enemy	2	4	4	5	5
Rules of Engagement	7	6	6	7	6
Fuel Remaining	6	7	5	2	4

Secondary Enemy Kill Decision

	4000+	3000-4000	2000-3000	1000-2000	0-1000
IDECIS	3	1	1	2	1
Fuel Remaining	1	4	4	1	2
Rules of Engagement	4	5	2	3	4
Danger	5	3	3	4	5
Speed	6	6	5	5	3
Range	2	7	6	6	-
Number of Enemy	7	2	7	7	7
MPG	8	8	-	8	6

Secondary Friendly Kill Decision

	4000+	3000-4000	2000-3000	1000-2000	0-1000
Number of Enemy	2	1	2	1	1
IDECIS	1	2	1	2	2
Speed	4	4	3	3	3
Rules of Engagement	3	5	6	7	5
Fuel Remaining	7	6	5	8	4
Danger	8	3	7	6	6
Range	6	7	4	4	7
MPG	6	8	-	5	8

APPENDIX G (continued)

VARIABLE RANKINGS FOR HOUR AND MISSION GROUPS

MISSION GROUP:

Primary Tactical Decision

	300+	200-300	100-200	1-100	0
MPG	7	1	1	1	7
Danger	3	2	2	2	2
Speed	1	3	3	5	3
Range	2	4	5	4	1
Number of Enemy	4	5	4	3	5
Rules of Engagement	5	7	6	6	6
Fuel Remaining	6	6	7	7	4

Secondary Enemy Kill Decision

	300+	200-300	100-200	1-100	0
IDECIS	1	1	1	1	1
Fuel Remaining	4	2	2	2	2
Rules of Engagement	6	4	3	3	4
Danger	5	3	4	4	5
Speed	7	7	6	5	3
Range	3	6	5	6	6
Number of Enemy	2	5	7	7	7
MPG	8	8	-	8	-

Secondary Friendly Kill Decision

	300+	200-300	100-200	1-100	0
Number of Enemy	1	2	1	2	1
IDECIS	5	1	2	1	2
Speed	6	7	3	3	3
Rules of Engagement	3	6	6	4	4
Fuel Remaining	8	4	8	5	5
Danger	4	3	7	6	6
Range	2	8	4	8	7
MPG	7	5	5	7	8

APPENDIX H

MULTIPLE CORRELATIONS OF PREDICTOR EQUATIONS WITH PREDICTED DECISION

	Primary Tactical Decision	Secondary Enemy Kill Decision	Secondary Friendly Kill Decision
Average Pilot	.6032	.6027	.4015
CDR	.5794	.5859	.4391
LCDR	.6236	.5654	.5299
LT	.6101	.6527	.3732
LT(jg)	.7568	.8193	.5284
Hours			
4000+	.4587	.7930	.5840
3000-4000	.6775	.5638	.4303
2000-3000	.6249	.5988	.5217
1000-2000	.6816	.6755	.3378
0-1000	.6062	.6190	.4442
Missions			
300+	.7459	.7052	.5128
200-300	.6402	.5748	.4524
100-200	.5778	.5915	.3397
1-100	.6309	.6677	.5309
0	.6213	.6143	.4499

```
      DIMENSION PT(900),ET(900),FT(900),TK(900)
      REAL LABEL/'    '/
      REAL*8 TITLE(12)/'NUMBER P','RIMARY R','IGHT VS ','NUMBER T','RIAL
     1S    ',7*'        '/,TETLE(12)/'NUMBER E','NEMY KIL','LS RIGHT',' V
     1S NUMB','ER PRIMA','RY RIGHT',6*'        '/,TFTLE(12)/'NUMBER F','
     1RIENDLY ','KILLS RI','GHT VS N','UMBER PR','IMARY RI','GHT     ',5
     1*'        '/
      COMMON SIT(64,6),MEM(64,3),PRICO(8),SECOEN(9),SECOFR(9),STARTP(8),
     1STARSE(9),STARSF(9),KOR(8),KORE(9),KORF(9),ISEED
      DATA NPRT,NPWT,NPR,NPW,NERT,NEWT,NER,NEW,NFRT,NFWT,NFR,NFW/12*0/
      CALL CANCEL(2)
READ SITUATIONS
      READ(5,1)((SIT(I,J),J=1,6),I=1,64)
READ INSTRUCTOR'S MEMORY
      READ(5,2)((MEM(I,J),J=1,3),I=1,64)
READ INSTRUCTOR'S PRIMARY AND SECONDARY COEFFICIENTS
      READ(5,3)(PRICO(I),I=1,8)
      READ(5,4)(SECOEN(I),I=1,9)
      READ(5,4)(SECOFR(I),I=1,9)
READ STUDENT'S PRIMARY AND SECONDARY STARTING COEFFICIENTS
      DO 1010 II=1,2
      READ(5,3)(STARTP(I),I=1,8)
      READ(5,4)(STARSE(I),I=1,9)
      READ(5,4)(STARSF(I),I=1,9)
      WRITE(6,8)(PRICO(I),I=1,8)
      WRITE(6,9)(SECOFN(I),I=1,9)
      WRITE(6,10)(SECOFR(I),I=1,9)
      WRITE(6,11)(STARTP(I),I=1,8)
      WRITE(6,12)(STARSE(I),I=1,9)
      WRITE(6,13)(STARSF(I),I=1,9)
SET STARTING SEED FOR RANDOM NUMBER GENERATOR
      ISEED=12345
      DO 1006 KOUNT=1,900
      CALL RANDOM(ISEED,RNDM)
PRESENT THE SITUATION
      I=RNDM*64.0+1.0
```

```
IS THE ENEMY POINTING AT THE FRIENDLY?

      DANGER=SIT(I,3)-AMOD(SIT(I,4)+180.0,360.0)
      DANGER=SIGN(DANGER,SIN(SIT(I,3)/57.2958))

SPEED DIFFERENTIAL

      SPEED=500.0*COS(SIT(I,4)/57.2958)-SIGN(450.0,COS(SIT(I,3)/57.2958)
     1)

RANGE AND FUEL RATIO

      RPG=SIT(I,2)/SIT(I,1)

MAKE PRIMARY DECISION

      IDECIS=STARTP(1)+.5+STARTP(2)*SIT(I,1)+STARTP(3)*SIT(I,2)+STARTP(4
     1)*SIT(I,5)+STARTP(5)*SIT(I,6)+STARTP(6)*DANGER+STARTP(7)*SPEED+STA
     1RTP(8)*RPG

GRADE PRIMARY DECISION

      CALL INSTRU(I,IPRI,IDECIS)

IS DECISION CORRECT?

      IF(IPRI.EQ.1) GO TO 1001
      NPWT=NPWT+1
      NPW=NPW+1

CORRECT THE PRIMARY DECISION COEFFICIENTS

      CALL KORECI(NPRT)
      GO TO 1000
 1001 NPRT=NPRT+1
      NPR=NPR+1

MAKE SECONDARY ENEMY DECISION

      IIEK=STARSE(1)+.5+STARSE(2)*SIT(I,1)+STARSE(3)*SIT(I,2)+STARSE(4)*
     1SIT(I,5)+STARSE(5)*SIT(I,6)+STARSE(6)*DANGER+STARSE(7)*SPEED+STARS
     1E(8)*RPG+STARSE(9)*FLOAT(IDECIS)

MAKE SECONDARY FRIENDLY DECISION

      IIFK=STARSF(1)+.5+STARSF(2)*SIT(I,1)+STARSF(3)*SIT(I,2)+STARSF(4)*
     1SIT(I,5)+STARSF(5)*SIT(I,6)+STARSF(6)*DANGER+STARSF(7)*SPEED+STARS
```

```
     1F(8)*RPG+STARSF(9)*FLOAT(IDECIS)
C
C GRADE SECONDARY ENEMY DECISION
C GRADE SECONDARY FRIENDLY DECISION
C
      CALL GRADER(I,ISECE,ISECF,IIEK,IIFK)
C
C IS DECISION CORRECT?
C
      IF(ISECE.EQ.1) GO TO 1002
      NEWT=NEWT+1
      NEW=NEW+1
C
C CORRECT THE SECONDARY ENEMY DECISION
C
      CALL KOREII(NERT)
      GO TO 1004
 1002 NERT=NERT+1
      NER=NER+1
C
C IS DECISION CORRECT?
C
 1004 IF(ISECF.EQ.1) GO TO 1003
      NFWT=NFWT+1
      NFW=NFW+1
C
C CORRECT THE SECONDARY FRIENDLY DECISION
C
      CALL KORFII(NFRT)
      GO TO 1000
 1003 NFRT=NFRT+1
      NFR=NFR+1
C
C
C COLLECT STATISTICS
C
C
 1000 KONT=(KOUNT/8)*8
      TK(KOUNT)=KOUNT*1.0
      PT(KOUNT)=NPRT*1.0
      ET(KOUNT)=NERT*1.0
      FT(KOUNT)=NFRT*1.0
      IF(KOUNT.NE.KONT) GO TO 1006
      PR=NPR/8.0
      PW=NPW/8.0
      PRT=NPRT*1.0/KOUNT
      IF(NPR.EQ.0) GO TO 1005
      ER=NER/(NPR*1.0)
```

```
      EW=NEW/(NPR*1.0)
      FR=NFR/(NPR*1.0)
      FW=NFW/(NPR*1.0)
 1007 IF(NPRT.EQ.0) GO TO 1008
      ERT=NERT*1.0/NPRT
      FRT=NFRT*1.0/NPRT
 1009 WRITE(6,5) KOUNT,NPRT,NERT,NFRT,PRT,ERT,FRT,PR,PW,ER,EW,FR,FW
      NPR=0
      NER=0
      NFR=0
      NPW=0
      NEW=0
      NFW=0
      GO TO 1006
 1005 ER=0.0
      EW=0.0
      FR=0.0
      FW=0.0
      GO TO 1007
 1008 ERT=0.0
      FRT=0.0
      GO TO 1009
 1006 CONTINUE
      WRITE(6,14)(STARTP(I),I=1,8)
      WRITE(6,15)(STARSE(I),I=1,9)
      WRITE(6,16)(STARSF(I),I=1,9)
      ITYPE=0
      MC=0
      NPTS=900
      EXSC=100.0
      YSCL=100.0
      IXUP=0
      IYRT=0
      MDXAX=0
      MDYAX=0
      IHIGH=8
      IWIDE=9
      IGRID=0
      CALL DRAW(NPTS,TK,PT,MC,ITYPE,LABEL,TITLE,EXSC,YSCL,IXUP,IYRT,MDXA
     1X,MDYAX,IWIDE,IHIGH,IGRID,LAST)
      CALL DRAW(NPTS,PT,ET,MC,ITYPE,LABEL,TETLE,EXSC,YSCL,IXUP,IYRT,MDXA
     1X,MDYAX,IWIDE,IHIGH,IGRID,LAST)
      CALL DRAW(NPTS,PT,FT,MC,ITYPE,LABEL,TFTLE,EXSC,YSCL,IXUP,IYRT,MDXA
     1X,MDYAX,IWIDE,IHIGH,IGRID,LAST)
      NPRT=0
      NPWT=0
      NERT=0
      NEWT=0
```

```
      NFRT=0
      NFWT=0
 1010 CONTINUE
    1 FORMAT(6X,F4.0,10X,F2.0,8X,F3.0,7X,F3.0,7X,F1.0,9X,F1.0)
    2 FORMAT(6X,I1,1X,I4,1X,I4)
    3 FORMAT(7F7.5,F9.5)
    4 FORMAT(7F7.5,F9.5,F8.5)
    5 FORMAT(' ',4I6,9F12.8)
    8 FORMAT('1','INSTRUCTOR PRIMARY:',8F12.8)
    9 FORMAT(' ','INSTRUCTOR ENEMY:',9F12.8)
   10 FORMAT(' ','INSTRUCTOR FRIEND:',9F12.8,/)
   11 FORMAT(' ','STARTING PRIMARY:',8F12.8)
   12 FORMAT(' ','STARTING ENEMY:',9F12.8)
   13 FORMAT(' ','STARTING FRIEND:',9F12.8,/)
   14 FORMAT('0','FINAL PRIMARY:',8F12.8)
   15 FORMAT(' ','FINAL EMENY:',9F12.8)
   16 FORMAT(' ','FINAL FRIEND;',9F12.8)
      STOP
      END
```

```
      SUBROUTINE INSTRU(I,IPRI,IDECIS)
      COMMON SIT(64,6),MEM(64,3),PRICO(8),SECOEN(9),SECOFR(9),STARTP(8),
     1STARSE(9),STARSF(9),KOR(8),KORE(9),KORF(9),ISEED
      IPRI=1

IS THE DECISION CORRECT?

      IF(IDECIS.EQ.MEM(I,1)) RETURN
      IPRI=0
      DO 1000 J=1,8
      X=SIGN(1.0,STARTP(J))
      Y=SIGN(1.0,PRICO(J))

WRONG SIGN

      IF(X.EQ.Y) GO TO 100
      KOR(J)=0
      GO TO 1000

TOO LARGE

  100 IF(STARTP(J).GE.PRICO(J)) GO TO 101
      KOR(J)=1
      GO TO 1000
  101 IF(STARTP(J).EQ.PRICO(J)) GO TO 102

TOO SMALL

      KOR(J)=2
      GO TO 1000
  102 KOR(J)=3
 1000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GRADER(I,ISECE,ISECF,IIEK,IIFK)
      COMMON SIT(64,6),MEM(64,3),PRICO(8),SECOEN(9),SECOFR(9),STARTP(8),
     1STARSE(9),STARSF(9),KOR(8),KORE(9),KORF(9),ISEED
      ISECE=1
      ISECF=1
C IS THE DECISION CORRECT?
      IF(IIEK.EQ.MEM(I,2)) GO TO 100
      ISECE=0
      DO 1000 J=1,9
      X=SIGN(1.0,STARSE(J))
      Y=SIGN(1.0,SECOEN(J))
C WRONG SIGN
      IF(X.EQ.Y) GO TO 101
      KORE(J)=0
      GO TO 1000
C TOO LARGE
  101 IF(STARSE(J).GE.SECOEN(J)) GO TO 103
      KORE(J)=1
      GO TO 1000
  103 IF(STARSE(J).EQ.SECOEN(J)) GO TO 105
C TOO SMALL
      KORE(J)=2
      GO TO 1000
  105 KORE(J)=3
 1000 CONTINUE
C IS THE DECISION CORRECT?
  100 IF(IIFK.EQ.MEM(I,3)) RETURN
      ISECF=0
      DO 1001 J=1,9
      X=SIGN(1.0,STARSF(J))
      Y=SIGN(1.0,SECOFR(J))
C WRONG SIGN
      IF(X.EQ.Y) GO TO 102
      KORF(J)=0
```

```
      GO TO 1001
C TOO LARGE
  102 IF(STARSF(J).GE.SECOFR(J)) GO TO 104
      KORF(J)=1
      GO TO 1001
  104 IF(STARSF(J).EQ.SECOFR(J)) GO TO 106
C TOO SMALL
      KORF(J)=2
      GO TO 1001
  106 KORF(J)=3
 1001 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE KORECI(X)
      COMMON SIT(64,6),MEM(64,3),PRICO(8),SECOEN(9),SECOFR(9),STARTP(8),
     1STARSE(9),STARSF(9),KOR(8),KORE(9),KORF(9),ISEED
SET EXPERIENCE MODIFIER FACTOR
      CALL RANDOM(ISEED,ZZ)
      ZZ=ZZ/(10+.1*X)
      DO 1000 J=1,8
      K=0
DOES THIS STUDENT SHOW EXPERTISE?
      IF(STARTP(J).EQ.0) CALL NOVICE(PRICO(J),STARTP(J),K)
      IF(K.EQ.1) GO TO 1000
      I=KOR(J)+1
      GO TO (100,101,102,104),I
CHANGE SIGN
  100 STARTP(J)=-1.0*STARTP(J)
      GO TO 1000
  101 IF(STARTP(J).LE.0) GO TO 105
INCREASE
  103 STARTP(J)=STARTP(J)*(1.0+ZZ)
      GO TO 1000
  102 IF(STARTP(J).LE.0) GO TO 103
REDUCE
  105 STARTP(J)=STARTP(J)*(1.0-ZZ)
 1000 CONTINUE
  104 RETURN
      END
```

```
      SUBROUTINE KOREII(X)
      COMMON SIT(64,6),MEM(64,3),PRICO(8),SECOEN(9),SECOFR(9),STARTP(8),
     1STARSE(9),STARSF(9),KOR(8),KORE(9),KORF(9),ISEED
C SET EXPERIENCE MODIFIER FACTOR
      CALL RANDOM(ISEED,ZZ)
      ZZ=ZZ/(10+.1*X)
      DO 1000 J=1,9
      K=0
C DOES THIS STUDENT SHOW EXPERTISE?
      IF(STARSE(J).EQ.0) CALL NOVICE(SECOEN(J),STARSE(J),K)
      IF(K.EQ.1) GO TO 1000
      I=KORE(J)+1
      GO TO (100,101,102,104),I
C CHANGE SIGN
  100 STARSE(J)=-1.0*STARSE(J)
      GO TO 1000
  101 IF(STARSE(J).LE.0) GO TO 105
C INCREASE
  103 STARSE(J)=STARSE(J)*(1.0+ZZ)
      GO TO 1000
  102 IF(STARSE(J).LE.0) GO TO 103
C REDUCE
  105 STARSE(J)=STARSE(J)*(1.0-ZZ)
 1000 CONTINUE
  104 RETURN
      END
```

```
      SUBROUTINE KORFII(X)
      COMMON SIT(64,6),MEM(64,3),PRICO(8),SECOEN(9),SECOFR(9),STARTP(8),
     1STARSE(9),STARSF(9),KOR(8),KORE(9),KORF(9),ISEED
C SET EXPERIENCE MODIFIER FACTOR
      CALL RANDOM(ISEED,ZZ)
      ZZ=ZZ/(10+.1*X)
      DO 1000 J=1,9
      K=0
C DOES THIS STUDENT SHOW EXPERTISE?
      IF(STARSF(J).EQ.0) CALL NOVICE(SECOFR(J),STARSF(J),K)
      IF(K.EQ.1) GO TO 1000
      I=KORF(J)+1
      GO TO (100,101,102,104),I
C CHANGE SIGN
  100 STARSF(J)=-1.0*STARSF(J)
      GO TO 1000
  101 IF(STARSF(J).LE.0) GO TO 105
C INCREASE
  103 STARSF(J)=STARSF(J)*(1.0+ZZ)
      GO TO 1000
  102 IF(STARSF(J).LE.0) GO TO 103
C REDUCE
  105 STARSF(J)=STARSF(J)*(1.0-ZZ)
 1000 CONTINUE
  104 RETURN
      END
```

```
      SUBROUTINE NOVICE(X,Y,K)
      COMMON SIT(64,6),MEM(64,3),PRICO(8),SECOEN(9),SECOFR(9),STARTP(8),
     1STARSE(9),STARSF(9),KOR(8),KORE(9),KORF(9),ISEED
C     GENERATE A STARTING COEFFICIENT IN INTERVAL(-30,30)
      CALL RANDOM(ISEED,Y)
      Y=30.0*Y
      Y=SIGN(Y,X)
      K=1
      RETURN
      END
```

```
      SUBROUTINE RANDOM(ISEED,YFL)
GENERATE A RANDOM NUMBER WHICH IS U(0,1)
      ISEED=ISEED*65539
      IF(ISEED) 5,6,6
    5 ISEED=ISEED+2147483647+1
    6 YFL=ISEED*.4656613E-9
      RETURN
      END
```

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13. ABSTRACT

The evaluations made by 36 Navy fighter pilots of 64 air-to-air combat situations are statistically analyzed to detect any significant differences between pilots' evaluative techniques in relation to their rank, flight hours and combat missions. Predictor equations are computed and used in a self-analyzing, self-modifying artificial intelligence program modeled on an instructor-flight student interactive situation.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Evaluation Techniques						
Decision Making						
Naval Aviator						
Fighter Pilot						
Self Analyzing Programs						
Self Modifying Programs						
Flight Instruction						

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